OPTIMIZING CRISIS ACTION PLANNING IN THE NONCOMBATANT EVACUATION OPERATION SETTING

GRADUATE RESEARCH PROJECT

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Abstract

European Command (EUCOM) Plans and Operations Center is responsible for developing EUCOM joint and combined warfighting capability, specifically any contingency planning for Noncombatant Evacuation Operations (NEO) that may occur in and around the EUCOM area of responsibility. Due to the special political and diplomatic sensitivities that surround a NEO, the EUCOM/J3 desires a more refined and intricate method to capture the complexity of the NEO – especially when inefficiencies in the process rise to the attention of the world media sources. This research's strategic goal was to increase command resource efficiency and decrease evacuation time. Further, the research objectives included improving the joint planners' insight into building more robust contingency and operational plans; highlighting chokepoints, bottlenecks, flow limiters, and options to quicken queues; and identifying resources and transportation mediums that display the most sensitivity to policy changes. These objectives were addressed by exploring topics in NEOs, evacuation planning, queueing systems, and modeling techniques and applications – particularly in computer simulation. The method chosen to model the NEO system and thus achieve the research objectives was a discrete event simulation model translated by the use of the Arena® simulation software. The model was developed by using a 12-Step simulation study procedure. Due to the lack of sufficient input data, the created model was unable to be fully validated; yet several insightful results were gleaned from the planned experiments. Specifically, the model was able to replicate a NEO's complexity and identify several areas where evacuee flow is constrained. It also highlights how to more effectively distribute command-controlled resources.

To my ever-stalwart husband and our future organized math whiz.

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Aimee Nicole Gregg

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OPTIMIZING CRISIS ACTION PLANNING IN THE NONCOMBATANT EVACUATION OPERATION SETTING

Chapter 1. Introduction

1.1. Background

In the spectrum of military operations, a type of operation the Department of Defense (DoD) performs is Military Operations Other Than War (MOOTW). A special case of MOOTW is the Noncombatant Evacuation Operation (NEO). The objective of a NEO is to assist the Department of State (DoS) with the prompt evacuation of select persons from within a foreign nation to a previously determined safe haven (SH)[1] due to humanitarian, diplomatic or political reasons which are threatening the lives of said persons. Those eligible for this assistance include U.S. citizens, DoD and DoS civilian personnel, and designated host nation (HN) and third country nationals (TCN). NEOs have two unique characteristics among military operations. First, a NEO is ordered by a DoS official, usually the U.S. Ambassador of the host nation, who becomes the senior authority for the operation; thus making a government civilian responsible for the success of the operation and the evacuees' safety (JP 3-68, 2007: ix). Second, the often tenuous and dynamic political and diplomatic influences of a NEO significantly shape its procedures and sequencing (JP 3-68, 2007: ix).

[1] Each operation's conditions extend to the optimal choices for a safe haven. The contiguous United States (CONUS) or a U.S. protectorate usually serves as a preferred NEO end point (JP 3-68, 2007: VII-3-4).

Although each NEO shares commonalities, each instance of an evacuation operation is always a unique occurrence. The external environment dictates the flow of a NEO, and thus the actual operation begins by inserting evacuation, stabilization, and possibly security forces (Muñoz-Avila et al., 1999: 289-90). The next major phase consists of the forces temporarily occupying portions of the host foreign nation – usually the U.S. Embassy and transportation depots (Muñoz-Avila et al., 1999: 290). As far as the DoD is concerned, the last major stage is a timely withdrawal of those forces when the operation has accomplished its mission (Muñoz-Avila et al., 1999: 290). The geographic component commander (GCC) may establish a joint task force (JTF) to plan for expected scenarios and to deploy and redeploy forces for a NEO (JP 3-68, 2007: I-2). As stated above, an Ambassador retains the authority for operation conduct as opposed to the commander joint task force (CJTF).

Muñoz-Avila, et al. (2007: 290) discuss how a NEO applies to all three levels of planning: strategic, operational and tactical. At the broadest perspective, decision makers have to determine if it is strategically wise to perform the NEO at all (Muñoz-Avila et al., 1999: 290). Next, the JTF must be sized and organized. As a distinct characteristic, the size of this JTF varies greatly with each NEO and is dependent on the availability and responsiveness of potential forces (Muñoz-Avila et al., 1999: 290). Finally, at the tactical level, planning is narrowed down to precisely assigning tasks to resources (Muñoz-Avila et al., 1999: 290). Specifically, Joint Publication (JP) 3-68 *Noncombatant Evacuation Operations,* 22 January 2007, governs general NEO planning considerations; yet, the operation's specific needs, resource constraints, and pertinent

NEO lessons learned will further refine planning and execution. (Muñoz-Avila et al. 1999: 290).

From the operations research (OR) high-level viewpoint, each NEO is simply a series of lines (i.e., queues) where evacuees await transportation – either by land, air or sea – through a semi-established network of assembly points, evacuee processing centers, and embarkation/debarkation ports (e.g., Sea/Surface Port of Embarkation/Debarkation (SPOE/SPOD) and Aerial Port of Embarkation/Debarkation (APOE/APOD)). The NEO network can be further broken down into several repetitive segments of the same procedure consisting of (1) processing at a new arrival point; (2) processing to obtain next transport; (3) awaiting availability of next transportation medium and (4) traveling to next arrival point. It is important to note that all of these stations only have finite resources (servers) to wait on each evacuee. These resources are further specified and explained as pertains to our NEO system in Chapter 3. With the realization of this abstraction, the best way to study a NEO system is through queueing theory and a representative mathematical model using discrete-event simulation.

The request for this research stems from the European Command (EUCOM) J3 Plans and Operations Center (EPOC)[2] as that unified command's focal point for joint and combined warfighting capability. Because it ensures these capabilities through operational directives, plans, orders, and joint training and exercises; these planning functions must be executed in the most realistic degree to achieve a high level of effectiveness and to refine their standard operating procedures for each warfighting

[2] ECJ3/EPOC directs development and execution of operations in support of U.S. interests and regional alliance in the USEUCOM Area of Responsibility (AOR)/Area of Interest (AOI). (Electronic Message, 24 Mar 10)

category. Also, they are European Command's primary conduit between the National Command Authorities (NCA), the Joint Staff, North Atlantic Treaty Organization (NATO), U.S. European Command (USEUCOM) and subordinate commands for operations information and requirements. (Electronic Message, 24 Mar 10)

Further, EUCOM's mission is "to conduct military operations, international military partnering, and interagency partnering to enhance transatlantic security and defend the U.S. forward" (Mission & Vision, 2010). The purpose of EUCOM since its conception is to demonstrate U.S. commitment to the protection of Western Europe and to reinforce democracy and aid alliance nations often through the means of humanitarian and peace-keeping operations (A Brief History, 2010); thus supporting the 51 countries in its AOR and surrounding Eurasia and the Middle East by subordinating a military instrument of power (IOP) (i.e., MOOTW) to the broader diplomatic IOP such as a NEO is defined. To accomplish this task in a high-density AOR, EUCOM is split into the five components. These are: U.S. Army, Europe (USAEUR), U.S. Air Forces Europe (USAFE), Naval Forces, Europe (NAVEUR), Marine Corps Forces, Europe (MARFOREUR) and Special Operations Command Europe (SOCEUR); these components ensure and support the EUCOM and EPOC mission (A Brief History, 2010). The roles of EUCOM and EPOC provide profound justification for discovering and fixing NEO process inefficiencies and being able to share any generalized conditions with other GCCs and allies.

U.S. actions, as the unipolar power, in any urgent situation are carefully watched as other countries and nation states play their actions and assurances off U.S. response. Thus, when unstable political environments develop – especially those threatening to transform into civilian and/or military violence, the U.S. must chose its course of action carefully. In its leadership role, the US is wise to often act last to avoid a quicker and greater deterioration than a situation would actually warrant, and this decision making consideration certainly applies to the circumstances of a NEO. In accordance with the Federal Acquisition Regulation and Title 48 of the Code of Federal Regulations, the DoS has a firm rule to not enter into preemptive contracts for any logistical resources (e.g., transportation, food, water, petroleum, oil, and lubricants (POL), etc …) if there is only a chance of an emergency; so if an emergency occurs, the DoS personnel must execute these contracts in the midst of the turmoil (DoS 4 FAH-3 H-830, 2004: 1,6 and DoS 14 FAH-2 H-120, 2005: 1-3). Conversely, most other major countries (i.e., Great Britain, France, and Spain) do not limit themselves in this way (Livingstone, 2010). Coupling the Department of State's contract policy and the tendency to act last often leaves few external logistics resources (Moulton, 2010). For this reason, evacuation planning becomes that much more critical for U.S. forces supporting NEOs.

As subsets of evacuation planning, Major Christopher Blanchard, USMC, (1996) investigates deliberate and crisis action planning and their considerations with respect to a NEO. Even though EPOC's Crisis Response Branch directed this research; the fact is planners must thoroughly engage in both planning phases in order to execute a successful evacuation; thus emphasizing efforts in the planning for a given NEO scenario (i.e., deliberate planning) and in an actual happening or imminent scenario (i.e., crisis action planning). Blanchard (1996) stresses the political sensitivities and consequences that surround a NEO, yet the lives of U.S. citizens balance the operation's complexities and provide the motivation to attend to its planning issues.

1.2. Problem Statement

Due to the uncertainty inherent in a NEO and crisis action planning as described above, EUCOM/EPOC planners desire a more intricate and explanatory approach to describing the general NEO process (i.e., for any AOI). Specifically, the EUCOM/J3 hopes to shape real world MOOTW operations into repeatable, visibly-positive events throughout the command's area of operations (AOO). Forward progress in a NEO should be as discernible by the international press corps and their viewers as it is by the DoD service and DoS members responsible for carrying out the operation such that public affairs reports favorably highlight U.S. military forces' effectiveness during a crisis situation. Some relevant examples of crisis response planning are found in Federal Emergency Management Agency's (FEMA) and the U.S. Government's (USG) handling of and response to Hurricane Katrina, the Haiti earthquake, and the recent British Petroleum (BP) oil spill in the Gulf of Mexico. These events received an ample amount of negative press; thus, public confidence in the lead agency's competence diminished and lowered the mission's perceived progress.

In creating a model, this representation will seek to replicate a general NEO in order to describe and understand the process and further to find the areas causing, or most likely to cause, delays or complications in the process. Ultimately, these insights will underscore process areas where efficiencies can be gained. Together this knowledge will provide insight to the EUCOM/J3 for enhanced allocation of command resources and for areas to concentrate diplomatic efforts with the pertinent countries.

1.3. Scope and Assumptions

The scope of this research reduces the problem via three interest areas: (1) the NEO's geographical area/location; (2) the portion of the NEO process with which EUCOM is most concerned; and (3) the operational environment as defined by JP 3-68 under which the NEO is conducted. By describing a general NEO situation, the model must be flexible enough to incorporate the details of distinct contingency plans (CONPLAN) from different AORs. Therefore, each segment incorporates variable capacities and travel time, especially where the travelling leg is concerned. Next, the NEO process spans a very wide collection of DoS and DoD activities and a timeframe over several years. EUCOM/ECJ3 has questions concerning certain points in the actual execution process, so the NEO portion will be defined to include these points. In this research, the start of the NEO is defined as the point where the Department of State orders the operation, which subsequently allows the GCC to create a JTF to deploy U.S. forces, usually beginning with a Forward Control Element (FCE) to the country in distress. The model's end point is the point where evacuees travel to the final, or terminating, SH. Even though the planners are most interested in culminating at the intermediate or temporary safe haven (ISH/TSH); the model will continue on in order to best observe any throughput and capacity issues stemming from the intermediate safe haven. Last, knowing the existing operational environment in the host nation is crucial to properly organizing U.S. forces for the evacuation. For this research, the NEO is assumed to take place in a permissive environment where the CJTF can expect the host nation government to agree to and support U.S.-led military operations as result of no apparent internal political or societal resistance to the evacuation (JP 3-68, 2007: I-2). As a result, CJTF can modify the composition of forces by decreasing its security element yet still be able to augment quickly with any indication of increased threats (JP 3-68, 2007: I-2).

1.4. Research Objectives and Contributions

Ideally, the ultimate goal of this and previous NEO studies is to produce an estimate for how many persons a JTF could aspire to evacuate and in what time frame. However, achieving this goal is problematic given the varied inputs and sensitivity of those inputs to the overall model. More importantly, due to the sporadic occurrence, impending danger and short life of a NEO; these operations haven't recorded much of the vital input data (e.g., arrival rate of evacuees to assembly area or average evacuee load time for the different transportation medium hasn't been collected). The objectives of this research are threefold. Foremost, this effort will aspire to improve the crisis action planners' insight into building better CONPLANs and operations plans (OPLAN) by validating a simulation model as a representation of a general NEO from a specified beginning and end point. Second, the model highlights choke points, flow limiters and options to quicken queues. Finally, the research identifies the resources and transportation modes which display the most sensitivity when decreased execution time is concerned.

The overall benefit of this research is it will provide EUCOM an analytical framework for planning NEOs and learning how to address its common problems. Another advantage to the research is that the produced model will be able to address a multitude of questions and concerns that may arise during planning other NEO surroundings. Moreover, considering the joint nature of these operations, this universal NEO tool facilitates high-level planning where planners may not know the minute details of how the responsible service carries out its tasks but can input the general activities to get a thorough idea of a certain scenario's outcome. As stated earlier, the research's contributions will provide insight to the EUCOM/J3 for enhanced allocation of command resources and for areas to concentrate diplomatic efforts with the pertinent countries.

1.5. Preview

The remaining chapters contain a detailed explanation of the research methodology, an analysis of this methodology, and conclusions. Chapter 2 describes the literature pertaining to NEOs, evacuation planning, queueing theory and discrete event simulation reviewed during the project. In Chapter 3, the research assumptions, NEO procedures, and constraints are defined. It also contains a detailed description of the methodology used to generate the representative model and different scenarios investigated. Results and analysis are presented in Chapter 4. Finally, Chapter 5 lists the conclusions and recommendations of the research project.

Chapter 2. Literature Review

2.1. Introduction

This chapter first reviews literature, including technical, general, and government material, pertaining to a NEO and its planning considerations. To support the specific planning guidance provided from those documents, a short précis of evacuation planning theory is offered. Next, as was stated in Chapter 1, a NEO can clearly be viewed as a system of queues; thus a queueing theory summary offers the necessary framework to describe a basic queueing system and to outline what queueing structure would best model this system. Last, the different approaches to implement a mathematical model are described with examples of selected techniques from current technical publications specifically a section focusing on how to implement a mathematical model via simulation and its best practices.

2.2. NEO Specific Literature

The amount of recent NEO-specific literature is fairly limited in numbers and scope especially when examining technical studies of this operation type. First, the DoD documents joint doctrine for planning and tactics, techniques, and procedures (TTP) in JP 3-68 *Noncombatant Evacuation Operations*, 22 January 2007 and JP 3-07.5 *Joint Tactics, Techniques, and Procedures for Noncombatant Evacuation Operations*, 30 September 1997 respectively. Next, since the U.S. Navy and the U.S. Marine Corps (USMC) usually play a key role in the NEO force deployment and transporting evacuees, they have documented key NEO issues. For the technical works, three AFIT theses discuss NEO networks. Two dissertations (Gullett and Stiver, 1980; Moncure and White, 1982) are concerned with NEO network evacuation capabilities. The other (Kostek, 1988) deals with concept mapping to describe the Decision Support System (DSS) of a NEO from Sudan; since this is unrelated to this research's framework, it will not be further discussed. Finally, a conference paper details a Defense Advanced Research Projects Agency (DARPA) study which compares evacuation plans and implements the NEO system using object-oriented animated modeling (Sumner and Zahn, 1996).

2.2.1. Government Publications

Both JP 3-68 (2007) and JP 3-07.5 (1997) provide NEO guidance for relevant agencies roles, coordination, and interaction; command and control; contingency and pre-deployment planning considerations; employment and evacuation operation procedures; evacuee processing; and intermediate staging base and safe haven operations. However, JP 3-07.5 (1997: i) concentrates on giving GCCs and CJTFs guidance for NEO planning and conduct. Whereas, JP 3-68 (2007) expands on multinational NEO conduct doctrine, explains the NEO tracking system (NTS), and addresses repatriation processing and operational risk issues. As with all doctrine, these publications are authoritative but depend on the commander and his planners to use their operational expertise and critical decision making skills to address specific needs and constraints of each NEO instance.

The U.S. Navy (USN) imparts operational knowledge from an individual service agency viewpoint. The Center for Naval Analyses and Adam Siegel (1991) produced a review and critique of Operation EASTERN EXIT, the January 1991 NEO from Mogadishu, Somalia. In this case, USN and USMC forces evacuated 281 persons from a volatile civil war environment in the capital city and completed the operation over ten days using only rotary wing aircraft (Siegel, 1991: v-vi). Seigel's (1991) lengthy account illustrates how each NEO execution greatly depends on its distinctive surroundings and how the rarity of NEOs adds to fog and friction of war. Additionally, Major Christopher Blanchard, USMC, (1986) wrote his Naval War College report on general NEO planning considerations. Blanchard (1986) explicitly notes the reasons why NEOs fall under the Department of State's control and emphasizes more attention and effort toward DoD and DoS coordination for NEOs to ensure more successful operations.

2.2.2. NEO Technical Publications

Due to the nature of technical research and number of studies, very few NEO system elements and environments are modeled. Two associated theses model the road and aerial port networks in Germany under the Cold War atmosphere. Then, Sumner and Zahn (1996) from TASC, Inc use the Integrated Model Development Environment (IMDE) software to model an evacuation from a South Pacific island due to a typhoon. Notably, each of the authors applied simulation to build their model.

From their Air Force Institute of Technology (AFIT) master's thesis, Captains Harry Gullett and Thomas Stiver (1980: 1) ascertain the completion time to evacuate all the noncombatants, including but not limited to military dependents, U.S. citizens, and DoS personnel, residing in the former Federal Republic of Germany (FRG) using two main APOEs, Rhein-Main Air Base and Munich Airport. They develop a computer simulation model to define the "structure of the existing NEO system", to determine the "interactions between and among the major subsystems", and to find "which subsystems are most sensitive to change" (1980: 4). Using a digital simulation technique with the language Q-GERT, which was developed for queueing problems within a network or Program Evaluation and Review Technique (PERT) setting, they investigate how completion time is affected by changing several factors of the ten major components of their NEO system listed in Table 1 (1980: 13-24). Gullett and Stiver (1980: 91) found weather, number of convoys, percent of available aircraft used, and the interaction of the two latter factors as significant to their response variable, time to empty the NEO network.

Table 1. Identified NEO Subsystems

Gullett & Stiver Major NEO Components	
1	NEO Population
2	Evacuation Ports
3	Evacuation Points
4	Road Networks
5	Railroad Networks
6	Aircraft
7	Supplies
8	Political/Military Environment
9	Weather
10	Communications

(Gullett and Stiver, 1980: 24)

Building on Gullett's and Stiver's research of the FRG evacuation port system, Captains Moncure and White (1982) continue the use of Q-GERT language in representing the NEO queues and network and expand the study to all six FRG APOEs. Specifically, their objectives include finding the portion of evacuees able to depart given various airlift capability and time to evacuate, referred to as the "overrun time," and finding the time to complete the evacuation using the full NEO network (1982: 5). They conclude that the aircraft service rate, overrun time, and the interaction of these two factors affect to a statistically significant level the number of the noncombatant population that can evacuate (1982: 53).

Referencing the 1996 Winter Simulation Conference, Sumner and Zahn (1996) sought to provide JTF planners the ability to compare several evacuation plans as part of crisis action planning; thus showing how tools can improve high-level military planning outputs in an environment of downsized budgets and forces. For the subject simulation, they put no restrictions on available resources and allowed several components of the evacuation plan to vary (1996: 967). Highlighted as complicating planning factors were where the evacuation point(s) would and could be set, transportation of evacuees to these points, loading times for each evacuee, and how long a non-full plane will wait (Sumner and Zahn, 1996: 968). These factors and later multi-leg sorties and platform maintenance activities were described in terms of object modeling elements yet, the rates and way of coding into IMDE were not fully expressed.

For their demonstration comparison, the completion times of two plans are figured. Parameters included number of evacuees (4,200), evacuation point/port (one), time JTF gives evacuation order (96 hours after NEO begins), number of operable AF bases (two – Kadena and Yokota AB), and type of aircraft (C-130H) (Sumner and Zahn, 1996: 972). The only true variable (i.e., difference between evacuation plans) was the number of available aircraft at each base, which was set at five for Plan A and three for Plan B; thus Plan B allowed for the contingency for unknown evacuees (Sumner and Zahn, 1996: 972). Once the JFC gave the evacuation order, then the evacuees were released to travel by their own means directly to the evacuation port and flown to a U.S. protectorate as the safe haven (Sumner and Zahn, 1996: 972). Plan A completed in 50 hours and Plan B in 80 hours of the evacuation order (Sumner and Zahn, 1996: 972). Thus proving that using ten aircraft as opposed to six was the quicker (and more efficient) plan; also with ten aircraft and other given resources, planners can expect the NEO to take about 6.083 days to move 4,200 evacuees.

2.3. Evacuation Planning

Similar to the NEO concept, evacuation planning is an area of study to aide local, state, and national governments respond to natural and man-made disasters (e.g., floods, earthquakes, tornadoes, hazardous materials spills, etc …) in order to save lives within its constituency. Sorensen and Vogt (1987) provide a comprehensive summary of evacuation planning and research for the integrated emergency management concept. This document gives considerable context to issues surrounding the NEO system and its content directly supports and provides a general validation for the planning guidance and TTPs given in the joint publications. Specifically, Sorensen and Vogt provide an analytical framework to enhance understanding of the hazard and of the resulting evacuation (1987: 3). The framework has five characteristics that are further broken down as shown in Table 2. Two planning areas of particular interest to the NEO system are organization and response issues. In particular they mention inadequacies in planning elements, evacuation personnel training, the technical basis for evacuation planning, physical factors that constrain, and public behavior exhibited (Sorensen and Vogt, 1987: 21-28). Additionally, they spell out common evacuation decisions as: "whether to notify, whether to evacuate, areas to evacuate, when to issue warning, channel to communicate, nature of recommendations and instructions, content of evacuation notifications, and when to return" (Sorenson and Vogt, 1987: 8).

Table 2. Evacuation Planning Areas

Analytical Framework	
1. Physical Hazard Characteristics	
	Ability to specify hazard parameters
	Ability to detect hazards
	Hazard dimensions
	Threat or risk of hazard
2. Warning Characteristics	
	Ability to alert
	Style and content of warning
3. Social Characteristics	
	Risk perceptions
	Ability to receive warnings
	Ability to evacuate
4. Organizational Characteristics	
	Planning and plans
	Training of evacuation personnel
	Technical basis for evacuation planning
5. Response Characteristics	
	Constraint to evacuation
	Public behavior
	Emergency worker behavior
	Evacuation as a public good

(Sorensen and Vogt, 1987: 4)

As the focus of this research is to add to the current knowledge, some publications that add to the technical basis for understanding evacuations include works by Hobeika and Kim (1998); Taafee, Kohl, and Kimbler (2005); Taaffe, Johnson and Steinmann (2006); and Pollak, Falash, Ingraham, and Gottesman (2004). First, Hobeika and Kim (1998) upgrade the mass evacuation computer program (MASSVAC), which is a virtual simulation, and compare its new algorithm efficiency in a nuclear power plant disaster setting. Next, Taaffe et al. (2005; 2006) both concentrate on evacuation of a hospital and its surrounding themes. Specifically, planners must improve hospital evacuation by exploring the "issues inherent in planning and evaluation" such as nature of the threat, risk to patients and staff, and continuing care and the "complexities of constructing appropriate models for emergency preparedness and evacuation" such as resource contention and facility-dependent activity times (Taaffe et al., 2005: 943). Building on previous findings, Taaffe et al. (2006) commit to using discrete-event simulation and the Arena® modeling language to model a hospital evacuation and investigates the effects from changes in the transportation, sheltering and staffing plans. Finally, Pollak et al. (2004) use discrete-event simulation by means of Arena® to further develop Department of Homeland Security's (HLS) integrated emergency response system by using OR to analyze and refine its standard operating procedures (SOP) and its emergency operations centers (EOC). The latter two works provide specific examples to aid in examining the NEO system and satisfying this study's objectives due to the similarity of their systems and objectives.

2.4. Queueing Theory

The key to appropriately and accurately representing a queueing system lies in understanding how to break the system into basic queueing processes. Hillier and Lieberman (2005) describe the basic queueing process below (see Figure 1).

> *Customers* requiring service are generated over time by an *input source*. These customers enter the *queueing system* and join a *queue*. At certain times, a member of the queue is selected for service by some rule known as the *queue discipline*. The requested service is then performed for the customer by the *service mechanism*, after which the customer leaves the queueing system. (Hillier and Lieberman, 2005: 766)

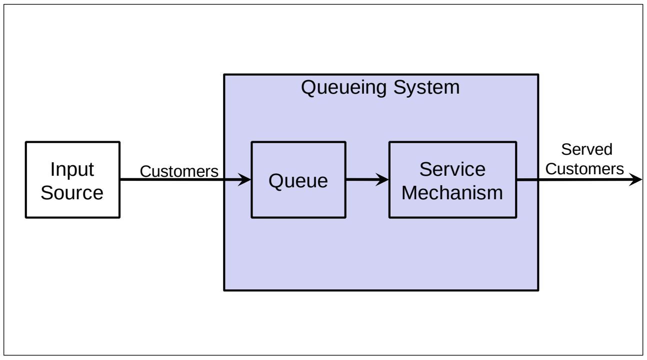

Figure 1. Basic Queueing System (Hillier and Lieberman, 2005: 766)

Additionally, the calling population determines the input source's size and is "the total number of distinct potential customers" for a queue (Hillier and Lieberman, 2005: 767). Rooted in statistics, queueing systems must specify the rate at which customers arrive, called the arrival rate, which is commonly given by the Poisson distribution; alternatively, the time between arrivals, called the interarrival time, commonly given by the exponential distribution can also be used to describe the customer arrival sequence (Hillier and Lieberman, 2005: 767). For the last major element of the queueing process, the service mechanism must be further defined by the number of service facilities, the layout of the facilities, and the number of parallel service channels at each facility (Hillier and Lieberman, 2005: 767).

The definitions, notations, and equations listed below complete the understanding of basic queueing theory. A queueing system's efficiency goal is to find the right amount of service capacity for system effectiveness; ultimately, optimizing a queueing system must include minimizing the cost of serving the customers and the 'cost' of waiting (Hillier and Lieberman, 2005: 765).

<u>Definitions</u>:

Balking	= customer behavior where s/he refuses to enter the system
Service time	= time elapsed from begin to end of service (a probability distribution)
State of system	= number of customers in queueing system; $N(t)$
Queue length	= number of customers waiting for service to begin
Utilization factor	= expected fraction of time the individual servers are busy
Events	= occurrences marking the end of arrivals or service times

<u>Notations</u>:

elementary queueing system = Interarrival time dist/Service time dist/# of servers

$N(t)$	= number of customers in queueing system at time t ($t \geq 0$).
$P_n(t)$	= probability of exactly n customers in queueing system at time t, given number of customers in queue at time 0.
s	= number of servers (parallel service channels) in queueing system

λ_n = mean arrival rate (expected number of arrivals per unit time) of new customers when *n* customers are in system.

μ_n = mean service rate for overall system (expected # of customers completing service per unit time) when *n* customers are in the system

ρ = utilization factor for the service facility

Equations:

Queue length = state of system – number of customers being served

$\rho = \lambda / (s\mu)$.

(Hillier and Lieberman, 2005: 768-770)

2.5. Modeling Approaches

When trying to address issues with real-world systems, the operations analyst must either experiment with the actual system or find a way to represent the real world such that some insight about the system can be achieved. Law and Kelton (2000: 4) discuss the different ways to represent a real system as by physical or mathematical models with mathematical being broken down into either an analytical solution or a simulation. Due to the nature of this field's research, operations analysis is mostly done using mathematical models instead of physical ones. The reason that the former approach is usually the preferred choice is because it "represents a system in terms of logical and quantitative relationships that are then manipulated and changed to see how the model reacts, and then how the system would react – *if* the mathematical model is a valid one" (Law and Kelton, 2000: 5). This result is the meat of what operations analysis has to offer the world and in this case - EUCOM about a NEO. If the problem can be reduced to a closed-form solution, then the analytical solution is the best option. However, if the problem's complexity prohibits this reduction, then simulation will be "the method of last resort" (Law and Kelton, 2000: 5). Although simulation can wholly consist of predetermined (i.e., deterministic) or random (i.e., stochastic - which will be expanded upon in section 2.5.2.) elements, a simulation usually has to represent at least one random feature of a system due to the increasing complex nature of systems. Thus, simulation is most commonly a realization of stochastic modeling.

2.5.1. Deterministic Modeling

To explain further, a deterministic model contains no component that associates its condition with a probability of being in that condition. Thus, in the deterministic setting, once the quantitative relationships of the mathematical model mentioned above are specified and the input variables are assigned values, then the output of the model is "determined" (Law and Kelton, 2000: 6). In simpler terms, the model just solves a system of equations; albeit solving them could require a considerable amount of time and computing power. In the next section, linear programming is offered as a potential deterministic modeling approach to the describing the NEO system. Specifically, linear programming requires the objective and the constraint functions to be linear and uses the simplex method to solve the system of *linear* equations.

2.5.1.1. Linear Programming and Network Flows

In thinking about the NEO system, it is comprised of (1) a finite number of points where evacuees arrive to, depart from or both arrive to and depart from; (2) one or more routes originating and ending at these points, which are traversed using various mediums (air, land, and sea transportation modes); and (3) a limited amount of evacuees that can be transported on these routes. These characteristics are analogous to the network model structure and its basic elements of nodes, arcs, and arc capacities respectively. An important characteristic about a system that follows the network structure is its critical path. Hillier and Lieberman (2005: 415) define a critical path as "the longest path through a project network, so the activities on this path are the critical bottleneck activities where any delays in their completion must be avoided to prevent delaying project completion." Thus, in describing the NEO network, the critical path includes only those processes necessary to mission accomplishment which are the nodes and arcs that get an evacuee to the final safe haven. (The collection of its processes will also apply in describing a NEO as a system.)

Hillier and Lieberman (2005: 388-391) also state that a network flow model can be optimized to find the greatest amount of flow possible given a predefined network of nodes, arcs and capacities, known as the *maximum flow* problem. It also can be optimized given a set amount of nodes and arcs to find the *shortest path* (i.e. the minimal distance) for one object to travel from the network's origin to its destination (2005: 380-383). The goal is find a combination of the shortest path and the maximum flow of the NEO network as is a noted example in Cova and Johnson (2003) reviewed below.

Due to its complexity and uncertainty, the NEO network is dynamic in several ways. For a *maximum flow* problem, one or more arc's capacity is likely change while the network is still in use. For instance, this fluctuation could stem from using different transportation mode types for the same arc or varying space demands between evacuees. Thus, each arc would associate a range of values for its capacity. For the *shortest path* problem, the outlay of the nodes could also change while the network is in use thus changing the shortest path; for example, a diplomatic dispute/decision could suddenly cut off access to a previously defined node. So, network flow's common assumptions of knowing the complete network and its capabilities (i.e., capacities) are not met. The above events show the dynamic state of the NEO network and provide sufficient justification for the shortcomings of network optimization modeling to provide enough flexibility to properly represent the NEO system and achieve this research's objectives.

2.5.1.2. Network Flow Application

Cova and Johnson (2003) explore modeling evacuations as a strategy to manage an emergency using the network flow linear programming construct. They note the following transportation issues that result from the hazard (current or impending) and/or the evacuation itself: (1) difficulty in notifying evacuees, (2) travel delays, and (3) compromised transportation lifelines (Cova and Johnson, 2003: 579); all of which are relevant to the NEO problem and its model. They also highlight an evacuation's central challenge, goal, and solution as "routing people to safety"; "transforming critical intersections into uninterrupted flow facilities"; and determining an "efficient routing plan" respectively (Cova and Johnson, 2003: 580-1). All referenced techniques share a concentration on dynamic evacuee flow and route-choice modeling. Since an evacuation strains the network beyond its capacity, the goal and solution rely on network optimization which, in turn, logically leads to using the *minimum cost flow* model.

In reviewing previous works, the authors provide examples of some of the *minimum cost flow* problem's special cases - specifically the *maximum flow* and *shortest path* problems; they also define an "optimal set of disjoint routes between the supply and the demand[3] nodes as the greatest sum of the capacity/time ratios for each route" (Cova and Johnson, 2003: 581). The latter view aligns well with NEO objectives. Set in a complex road network, Cova and Johnson translate road traffic – mainly its intersections – into a

[3] In *Introduction to Operations Research*, Hillier and Lieberman define a supply node as a node where "the flow out of that node exceeds the flow into that node" – also known as a source or origin node and define a demand node as a node where "the flow into that node exceeds the flow out of that node" – also known as a sink or destination node (Hillier and Lieberman, 2005: 379).

network flow structure and use land-based routing[4] to optimize travel away from the hazard during an evacuation (Cova and Johnson, 2003: 580). They draw on an integer extension of the *minimum cost flow* problem called the evacuation routing problem (ERP) to derive routing plans for sample networks (Cova and Johnson, 2003: 584). However, their detailed applications do not apply to the NEO transportation network simply since an ERP assumes the network is limited to land-based travel.

2.5.2. Stochastic Modeling

Stochastic modeling uses a particular structure to represent an event or a system of events whose occurrence relies on probability theory. This type of event is called a stochastic process. In this case, the system exists in some state where the possible states forms a mutually exclusive set with a given probability of existing in each of these states (Hiller and Lieberman, 2005). Additionally, the system will change states with time (Miller, 2010a). The way a model simulates this randomness and represents the real system depends on the modeling technique employed. No matter what method is chosen, a simulation model must be developed by adhering to a iterative process to capture all the essential elements.   With the significant increase in computer capabilities, more techniques are becoming feasible choices for mainstream modeling. Currently, the four most plausible and employed techniques are discrete-event system simulation, systems dynamics, object-oriented simulation, and agent-based modeling.

[4] Lane-based routing plan restricts "select turning options at intersections to improve traffic flow away from a hazardous area" (Cova and Johnson, 2003: 580).

2.5.3. Simulation Development Steps

Several authors (Banks et al., 2005; Law, 2006; Ragsdale, 2008; Sánchez, 2006; Sargent, 2009) offer guidelines of how to turn a real world system into a computer simulation model. Although each method is different, each contains common elements of ensuring the problem is defined correctly; collecting data needed to answer the questions inherent to the problem; building assumptions and definitions around the agreed-upon model concept; build, verify, and validate a model with a iterative approach until the model performs as intended and like the real system. Then use a statistical model and experimental design to infer system understanding from system performance results and document model outputs, analysis results, and system conclusions.

Effective model building, according to Law (2006), requires that a model be a close approximation; however, it should not completely duplicate the actual system for duplication sake. Sánchez (2006: 2) complements this statement with his suggestion to make the model "as simple as possible, but no simpler" given the problem constraints and the intended objectives and analysis. Ragsdale (2008: 562) expounds on the use of statistical models and how decision makers now base their response on "solid empirical evidence" instead of possibly biased inputs for what-if analysis and single inputs for best- and worst-case scenarios. Finally, Sánchez (2006: 3) emphasizes the purpose of simulation modeling is "to simplify and abstract to gain insights". These general areas and pieces of advice were used to guide the development of the NEO system model.

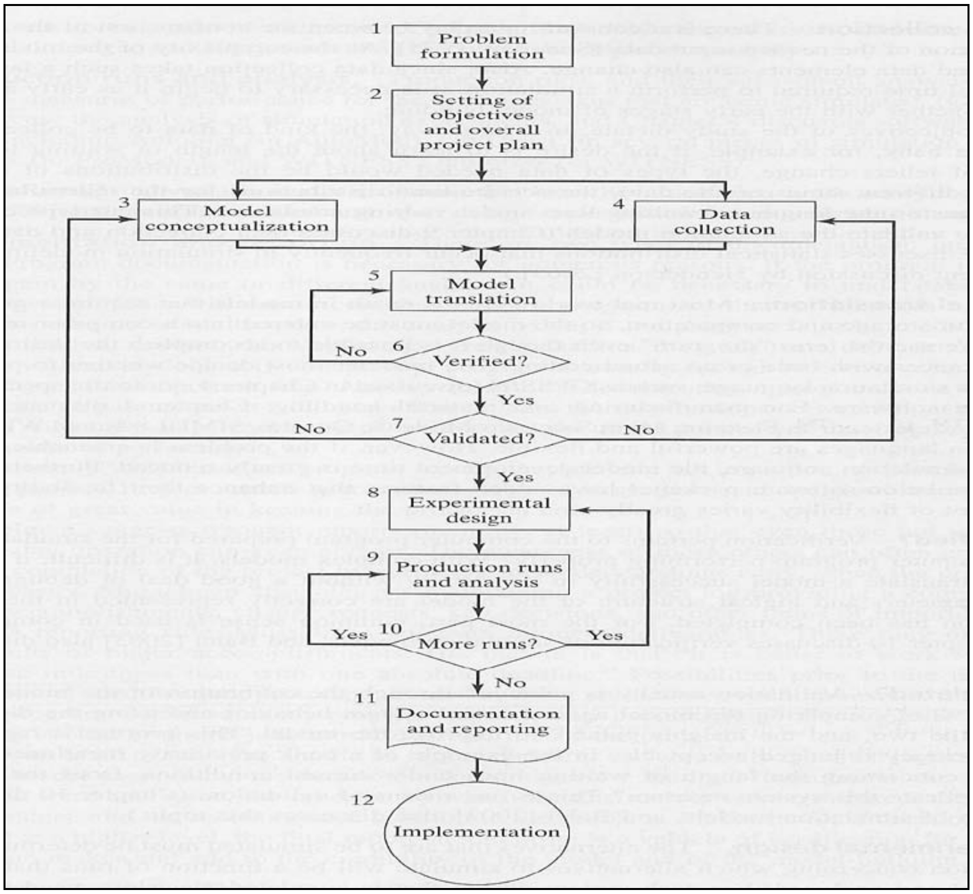

Figure 2. Simulation Steps (Banks et al., 2005: 15)

Due to its completeness and ensuing simplicity, the steps given by Banks et al., (2005) outline the methodology for accomplishing this research's objectives. Each step's name and description follows in the paragraphs below and are depicted as a process flowchart in Figure 2. For Steps 1 through 3, the core research method from Chapter 1 mimics their gist. Step 1 is *problem formulation* which is guided by the policymakers; often determining the appropriate clarification of the problem is also an iterative process to verify common understanding between the decision maker and the analyst (Banks et al., 2005: 14). Step 2 states to set the *project's objective and overall plan* by whittling down the possible ways to model the problem and the areas of interest to a determined methodology; then develop a concise set of questions to guide the model conceptualization (Banks et al., 2005: 14). Step 3 is *model conceptualization* where Banks et al. suggest starting simple and then add complexity only to the extent needed; they also admit that this skill is more talent and experience than a scientific exercise (Banks et al., 2005: 14). As Figure 2 displays, step 4, *data collection*, is visited and repeated often to aide in constructing the model concept (step 3) and later in steps 5 through 7. *Model translation*, Step 5, takes the model concept and collected data and transforms them using some sort of simulation language or software; the system to be modeled and the study's objectives determine which type and specific choice is optimal (Banks et al., 2005: 16). For *verification* (Step 6), the model must make sure the software or language is doing what it is intended to do; thus the arrow from this step back to *model translation* indicated that the model must be debugged and recoded if it is not correctly verified (Banks et al., 2005: 16). Law (2006: 64) directs that animation is a useful tool for *verification* by the visual inspection of the model's inner workings. To further add to the plausibility of the model, it must be *validated* as imitating the real system's outputs as well; Banks et al. (2005: 16) states this is best accomplished by calibrating the model's outputs against proven performance in the actual system. The best way to achieve *validation* for Step 7 relies on data availability. Since no historical NEO data exists that captures the needed parameter values and outputs, this study won't be able to fully attain this "most definitive test" of a model's validity as Law (2006: 63) declares.

For the steps to come, the developed-model is used to gain insights and inferences through experimentation, analysis and documentation. In Step 8, the various parameters that represent different options are explored and determined along with how the simulation will be run to capture the appropriate data and how many replications need to be run to ensure proper statistical significance in the results (Banks et al., 2005: 16). Once the experiments are designed, testing can begin with production runs and analysis where estimates for the study's measure of performances (MOP) are generated (Banks et al., 2005; 17). If these runs do not provide the needed results or other unexpected features need analyzed, Step 10 allows for completing more runs by adding to the production runs and designing more experiments (Banks et al., 2005: 17). The most important part of analysis is clearly documenting results and reporting these results back to the users and decision makers; Banks et al. also suggests recording any progress as the study proceeds such as software code commentary so the model can remain a living model and key inputs from meetings with subject matter experts (SME) (Banks et al., 2005: 17). The last step is *implementation*. In *implementation*, the fruits of the labor from all the previous steps hopefully come to fruition with the study's results applied to the real system. This is facilitated by and should be due to good communication with the study's sponsor throughout the model development and analysis. Finally, Banks et al. (2005: 18) groups these steps into four phases: "discovery and orientation period" (Steps 1-2);" model building and data collection" (Steps 3-7); "running the model" (Steps 8-10); and "implementation" (Steps 11-12). These groupings are used in Chapter 3.

2.5.3.1. Discrete-Event Simulation

For this type of stochastic simulation and the ones that follow, each type's definition, general structure and elements, advantages (versus the other types and in modeling the NEO system), and areas of application are described. According to Banks, Carson, Nelson, and Nicol (2005: 13) discrete-event system simulation or discrete-event simulation (DES) is "the modeling of systems in which the state variable changes only at a discrete set of points in time." Discrete refers to how the "state" of the system changes with respect to time; if a simulation is discrete, it represents state changes at discrete points in time as opposed to allowing the state to change continuously (Miller, 2010a). DES is generally described as "the dynamic processes of agent interaction simulated repeatedly over time" (Macal and North, 2009: 88). Also, a DES model can be built using different world views with the *process* and *event scheduling* views being most common (Sanchez, 2006: 5).

For its common uses, DES is used to "develop and execute models for the analysis of operational processes and system performance" (Pollak, 2004: 840). When using DES, it is important to validate the model (i.e., develop a model that truly represents the real world process and its performance) using accurate system historical data or estimates for system operating characteristics exists (Sweetser 1999: 1). Further, Sweetser (1999: 1) itemizes that DES is good for providing excellent process operation overview, for showing "where backlogs and queues form," and for estimating system performance given proposed system improvements. To introduce combinatorial complexity, Sterman (2001: 11) explains that systems with multiple solutions, nodes, inputs, or outputs – as exemplified in NEOs – embody this trait and are deemed complicated simply because they have so many possible combinations. DES can break down a combinatorial complex system "as a set of individual entities moving through a series of queues and activities in discrete time" (Tako and Robinson, 2009: 296). DES is chosen to implement this NEO system due to the typical uses of DES and its benefits in modeling a system. Expressly, the effect of changing the system can be tracked through changes in system performance; so the change in system function level can be accounted for, measured, and statistically analyzed to an adequate level of detail. Noted for its ability to characterize process flows (Taaffe, 2006: 511), the DES software, Arena®, is used in this research for model translation.

2.5.3.2. System Dynamics

System Dynamics (SD) is oft compared to DES as an alternative methodology to solving a systems-of-systems problem; yet SD has specific subtleties in how it performs and to what objectives it is best applied. According to the System Dynamics Society (2010), SD is "a methodology for studying and managing complex feedback[5] systems." A foundational SD concept is that system structure determines performance (Sweetser, 1999: 3); thus this must hold for the system in question. The four elements and also constructs of SD are feedback loops, stock and flow variables[6] which give accumulation, and time delays (Grossler et al., 2008: 376-377).

SD is purported to be best suited for describing problems of a strategic nature, for representing the macro view of the system, and for dealing with dynamic complexity[7] (Tako and Robison, 2009: 310; Sterman, 2001: 11). An advantage to using SD is being able to extract results without a heavy dependence on statistical analysis (Tako and Robison, 2009: 298). Last, when implementing SD, it is important to realize that SD

[5] Feedback refers to the property where system elements (e.g., X and Y) are both mutually dependent due to cause-and-effect interactions throughout the system (Grossler et al., 2008: 377). Yet, the relationship between X and Y cannot be isolated; rather only studying the whole system can provide an accurate representation of their correlation (Grossler et al., 2008: 377).

[6] Stock are variables whose level changes (increases and decreases) over time; flows are variables "which contain the mechanisms for state changes" (Grossler et al., 2008: 377).

[7] Sterman (2001: 11) defines dynamic complexity as "the often counterintuitive behavior of complex systems that arises from the interactions of the agents over time."

seeks to explain the cause-and-effect of decisions over extended time horizons (Grossler et al., 2008: 377) regularly expressed as the steady state of a system.

Because SD appears to be such a promising option to model the NEO system, limitations to making this connection are listed with respect to time horizon, complexity level, and data specificity. Looking at the system timeline, the NEO system clears out relatively quickly at each node and therefore has a short life-cycle and short feedback loops. Also, NEOs tend to begin and end quickly giving little time to assess the impact of policy or process decisions. As mentioned earlier, DES deals with the combinatorial complexity which a NEO mimics; placing NEO at a more detailed complexity level. Conversely, SD is best suited for dynamic complexity which requires a value for the limit as time extends to infinity. In short, NEOs are a short-term, tactical tool in a grander strategic plan – ill-suited for SD's feedback and long-view attributes. Finally, the structure of SD and its strategic-level focus limit the range of data analysis obtained (Sweetser, 1999: 6-7). DES models tend to provide several variable estimates of a quantitative nature from its stochastic assumptions (Tako and Robinson, 2009: 297). These DES outputs allow leaders and planners to assess the tactical impacts of performance on the overall system. SD, on the other hand, would likely not provide this level of fidelity in the data.

Nevertheless, it is important to note that typical managers often care more about what a model tells them than how to build the model (Tako and Robinson, 2009: 310). Ultimately, the modeler will choose the medium where the most can be learned. In the end, DES has better utility based on the nature of a NEO and types of data required to model and understand such unique events.

2.5.3.3. Object-Oriented Modeling

Object-oriented (OO) modeling represents an alternative view where the objects in a system, instead of system processes, form the basis for the model's construct and function (Miller, 2010b). Being the model's central element, an object needs two components in order to enable the system: attributes and methods; where attributes are defined as "variables that describe the state of the object" and methods are defined as "functions that specify its behavior" (Sumner and Zahn, 1996: 969) Respectively, these components are implemented with a *class file* containing the object's characteristics and *fields* containing the object's procedures, protocols, subroutines, etc … (Miller, 2010c). When using the OO construct, the model needs to have a standardized communication method, enabled by an application programming interface (API), so the object's structure and capabilities are known to each application (Sumner and Zahn, 1996). Furthermore, OO has four distinctive principles: it (1) uses *abstraction* to filter only important details for each object's instance and each simulation's purpose; (2) grants the same privileges to user-defined as built-in object types via *encapsulation*; (3) transfers class's functionality to subclasses through *inheritance* and (4) allows a function termed *polymorphism* where more than one method of the same name with different parameters can exist (Miller, 2010b).

The benefits to using OO models include its ability to reuse and share objects in a way that doesn't necessitate recoding. Thus, OO is more flexible than the other techniques in terms of being able to define elements in different models and use them interchangeably (Miller, 2010c). Sumner and Zahn (1996) concur with this view and choose to use OO to model their NEO system, which illustrates that OO is an appropriate technique for representing the NEO problem. However, their overall objective is to build an Object-oriented Database Management System of a service's (i.e., the Air Force) share of military operations such that a group of objects as those activities can interface within their overall program called IMDE (1996: 969). Thus, for the singular operation NEO, DES is still a very appropriate tool.

2.5.3.4. Agent-Based Modeling

The last major stochastic simulation technique addressed is agent-based modeling (ABM) where "agents repeatedly interact" (Macal and North, 2009: 88). ABM's main element, an agent, acts based on given protocols; is viewed similarly to how DES views entities; and is usually characterized by being an autonomous, self-directed, self-contained (i.e., modular), and social element (Macal and North, 2009: 87). Macal and North (2009: 88) further describe an agent as environmentally dependent, goal-oriented, adaptive, and resource-oriented as optional characteristics. Figure 3 displays the agent concept. ABM specializes in modeling complexity – especially interactions and dependencies of a system's agents; this trait also lends ABM, like SD, as an ideal way to model human and social behavior. Bonabeau (2002: 7280) notes some advantages of ABM as (1) a simple ABM can reveal complexity; (2) able to "capture emergent phenomena;" (3) "naturally describes a system;" and (4) "flexible". He also indicates four major application areas: flow, organizational, market, and diffusion simulation, where evacuations and traffic, hence NEOs, fall under flow.

In their Winter Simulation Conference presentation, Macal and North (2009) give some very simple applications of ABM in the games, "Life" and "Boids," which demonstrate use of rules to govern agent actions and interactions. Additionally, the latter game demonstrates emergent behaviors. For another Winter Simulation submittal, a panel discusses ABM in a Department of HLS application in mass egress and evacuation settings (Samuelson et al., 2007). Their research focused on improving crowd reaction and crowd management during terrorist-type crises and showed that ABMs can assist with crisis planning and use better evacuation route(s) and exit marking to influence human behaviors; thus increasing the efficiency of crowd withdrawal and reduce casualties (Samuelson et al., 2007: 1247, 1251). Although evacuees and their behaviors do affect the NEO system's performance, the goal of this research is not to model human behavior.

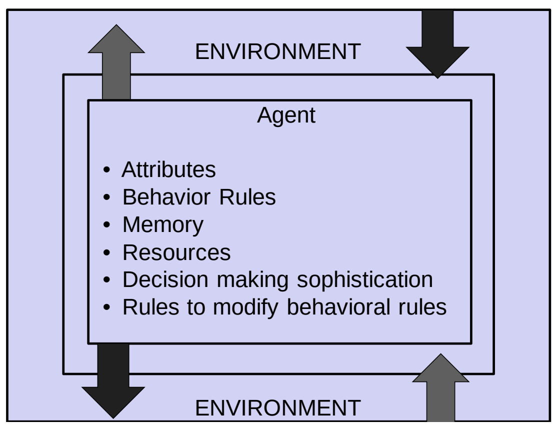

Figure 3. Agent Concept (Macal & North, 2009)

2.5.3.5. Additional Simulation Applications in Publication

The publication summaries below provided insight into the research of the NEO system from multiple aspects. Incorporating object-oriented modeling for their concept translation, Pidd, Silva, and Eglese (1996) and Gu and Mendonça (2006) attack evacuation planning problems. Pidd et al. (1996) deals more with the theory of evacuation planning by investigating a spatial DSS that is used to develop CONPLANs to aid traffic flow from disaster area evacuations. They also address three tactics (e.g., micro-, macro- and meso-simulators) analogous to the three military levels of operations for traffic simulators (1996: 415). Gu and Mendonça (2006) discuss similar limitations as the NEO system in that crisis action planners have a very tough task to gather data to make decisions on how to affect the on-going evacuation process. Since events of this scale rarely happen, they also mention that opportunities for learning from past observations are few and far between (2006: 554). The paper gives an excellent discussion on how to develop performance measures, specifically risk and level of severity, and shows how various factors affect group information foraging behaviors.

Wilson and Roe (2006) use DES to help the Transportation Security Administration (TSA) model airport security operations. They give a useful representation of entities as they flow through checkpoints and processes. Also they use animation to capture and let the user identify bottlenecks and troubled areas. This is modeled at a very low aggregation level (i.e., high detail); due to the strategic nature of the research, the NEO system won't be modeled to this level of detail. Another USG application and mentioned under section 2.3, Pollak et al. (2004: 840) wished to enhance the Department of HLS' emergency preparedness strategy planning and assessment capabilities by "verifying interoperability between entities, identifying gaps and bottlenecks in existing plans, enhancing resource utilization and plan functionality and rapidly exploring options to improve/refine plans." Morevoer, this is an excellent research resource for the NEO system since their objectives mirror ECJ3's goals; their documentation of model conceptualization and assumptions are superb and logical, and their addition of a graphical user interface (GUI) is a needed refinement for any operational tool.

Hay, Valentin, and Bijlsam (2006) use DES to model a generic hospital emergency room. They also employ Arena® to translate their model. They come to an important yet ironic conclusion that if the operating priority of a patient is ignored overall waiting times are reduced and higher-ranking doctors' utilization rates increase to a more suitable level (2006: 442). As referenced above under evacuation planning, Taaffe et al. (2006) uses DES and Arena® to "understand, analyze, and improve hospital evacuation plans." Their research provides framework for grouping the process, determining the appropriate goals of a sensitivity analysis and the actual cause of bottlenecks (2006: 511-513).

2.6. Synthesis

In summary, the NEO and evacuation planning literature led to the determination of which processes needed to be included in the NEO system and thus on an evacuee's critical path to the desired end point (i.e., final safe haven); also these references guided the layout of the overall process and the major sub-processes. Additionally, they provided current areas of concerns with the general NEO planning issues – especially those between the DoD and DoS. Furthermore, queueing theory; deterministic and stochastic modeling approaches; simulation modeling techniques and current applications of those techniques enhanced the model building, translation, and analysis efforts of this research. The collection of these sources supports the methodology to represent the NEO as a system of queues and to be modeled using discrete-event simulation. As well, this translation will be done with aide of computer simulation software Arena® due to its ease of use and forte in modeling process flows found in the NEO problem.

Chapter 3. Methodology

3.1. Introduction

This chapter first presents the background and particulars of how the NEO system is to be scoped such that it can be translated into a computer simulation. Then the chapter content follows the steps for a simulation development study given by Banks (2003) in Chapter 2. Specifically, this research is split into the same four phases: Phase I – Discovery and Orientation, Phase II – Model Building and Data Collection; Phase III – Running the Model; Phase IV – Implementation. Chapters 1 and 2 meet the requirements of Phase I, this chapter addresses Phases II and III; with the emphasis being on completely fulfilling Phase II and providing the foundation for Phase III which is the focus of Chapter 4.

3.2. Model Development

The following sections include all the definitions, assumption, and baseline scenario explanations and variable values such that this model can be replicated within Arena® if so desired. Together with further graphics and descriptions in Appendix A – C, this chapter fully describes the baseline state of the model. In section 3.3, the simulation steps from Chapter 2 are addressed in kind using the definitions and assumptions presented in section 3.2.

3.2.1. Definitions

3.2.1.1. NEO Joint Publications Terms

1. Ambassador **–** "A diplomatic agent of the highest rank;" this title is also called the senior DoS diplomatic agent or chief of mission (COM) (JP 3-68, 2007: I-2).

2. Emergency Action Plans (EAP) – Plan written for each embassy and consulate that includes a section which “addresses the military evacuation of U.S. citizens and designated foreign nationals”; pertinent questions that the EAP should answer are in Figure 4 (JP 3-68, 2007: xi).

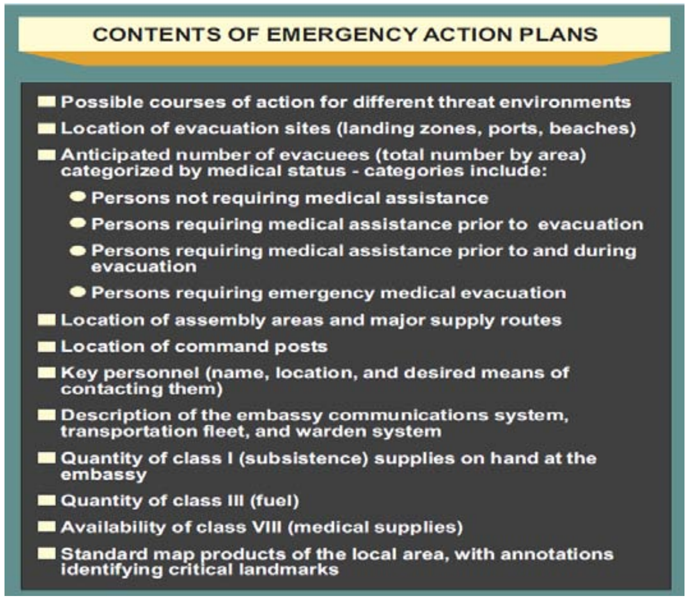

Figure 4. Emergency Action Plan Considerations (JP 3-68, 2007, IV-2)

3. Evacuation Control Center (ECC) – A physical place where evacuees are first introduced into the NEO system and various processing steps are accomplished as shown in Figure 5 below. DoS personnel control all actions within the ECC except for baggage collection and NTS stations; but some stations are manned by DoD personnel. (JP 3-68, 2007: VI-1-3)

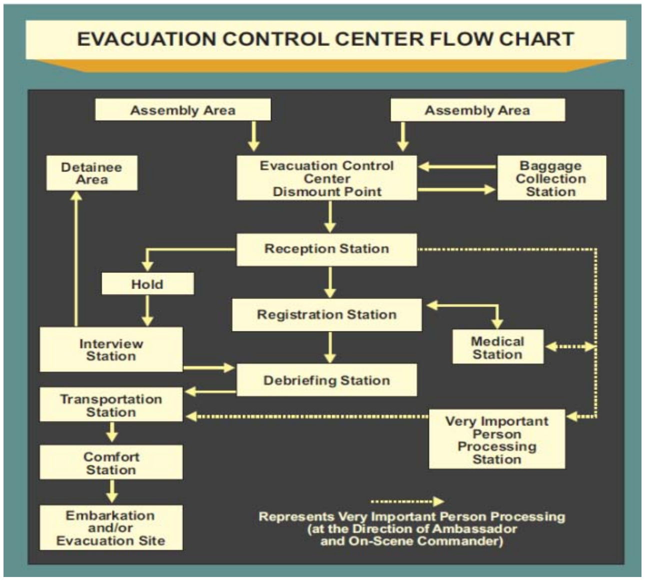

Figure 5. Evacuation Control Center Flow Chart (JP 3-68, 2007: VI-2)

4. Evacuee – "A civilian removed from a place of residence by military direction for reasons of personal security or the requirements of the military situation" (JP 3-07.5, 1997).

5. Host Nation (HN) – "A nation which receives the forces and/or supplies of allied nations and/or NATO organizations to be located on, to operate in, or to transit through its territory" (JP 3-07.5, 1997).

6. Host Nation Support (HNS) – "Civil and/or military assistance rendered by a nation to foreign forces within its territory during peacetime, crises or emergencies, or war based on agreements mutually concluded between nations" (JP 3-07.5, 1997).

7. Joint Task Force (JTF) – "A joint force that is constituted and so designated by the Secretary of Defense, a combatant commander, a subunified commander, or an existing joint task force commander" (JP 3-07.5, 1997).

8. Noncombatant Evacuees – "1. U.S. citizens who may be ordered to evacuate by competent authority include: a. Civilian employees of all agencies of the USG and their dependents, except as noted in 2a below. B. Military personnel of the U.S. Armed Forces specifically designated for evacuation as noncombatants. C. Dependents of member of the U.S. Armed Forces. 2. U.S. (and non-U.S.) citizens who may be authorized or assisted (but not necessarily ordered to evacuate) by competent authority include: a. Civilian employees of USG agencies and their dependents, who are residents in the country concerned on their own volition, but express the willingness to be evacuated. B. Private U.S. citizens and their dependents. C. Military personnel and dependents of members of the U.S. Armed Forces outlined in 1c above, short of an ordered evacuation. D. Designated aliens, including dependents of persons listed in 1a through 1c above, as prescribed by the Department of State" (JP 3-07.5, 1997).
9. Safe Haven – "Designated area(s) to which noncombatants of the United States Government's responsibility, and commercial vehicles and material may be evacuated during a domestic or other valid emergency" (JP 3-07.5, 1997).
10. Warden System – "An informal method communication used to pass information to U.S. citizens during emergencies" (JP 3-07.5, 1997).

3.2.1.2. Queueing Theory Specific Definitions

1. The *queueing system* is the NEO system consisting of several processes and queues to be detailed later in section 3.2.1.4.

2. Evacuees or the transportation mediums[8] are the *customers*.
3. The *input source* is all the surrounding areas in the HN from where evacuees come.
4. The *queue discipline* is first come, first served (FCFS). (This is the default for Arena®.)
5. The *service mechanisms* vary throughout the system along with the service facilities, and parallel service channels; all these will also be detailed in Tables 6 and 7 in section 3.2.1.4.
6. The State Department's F-77 report supplies an estimate of the *calling population* for a particular geographical region. Because these estimates are known to be inaccurate; this estimate should be used as a point with a range of error.
7. Interarrival Times – this is the time between arrivals. These times will depend on the assumed evacuation policy of the evacuees. These arrival rates will come from the uniform and triangular distributions (see Table 9).
8. Service Rates – these will be defined as stochastic and deterministic times. For the stochastic times only the uniform distribution is utilized. See Tables 6 and 7.

3.2.1.3. NEO Scenario Description

This NEO system is set in the following scenario. The HN is the fictional country of Petoria where Petoria is a coastal country. The descriptor of coastal country means that the host nation's resources include a port, and this port has direct access to the open ocean. The assembly point as given by the Warden System is collocated with the ECC.

[8] Transportation mediums are assumed to be means of transporting the evacuees to include buses, trucks, other vehicles, ships, amphibious vehicles, helicopters, or fixed-wing aircraft.

The first link in the NEO system is from the ECC to the SPOE; this movement is accomplished by some sort of land transportation using the same type of vehicle for all trips. Being the most optimal way to evacuate the country, the SPOE is a sea port. Thus, the next link from the SPOE to the TSH is completed by sea travel using military or commercial shipping mediums. These mediums are assumed to have equal capacities. The JTF must employ the concept of a temporary safe haven because the SPOE resources are not adequate enough to achieve the speed of evacuation that is desired by the COM and CJTF. The TSH is an island country or nation state and has limited space resources for hosting evacuees. The next link is from the TSH holding area to the APOE (i.e., an airport). The TSH and the APOE are not collocated; so movement between these points requires land transportation. Again, these land transportation mediums are set as the same type. Finally, the last link is from the APOE to the SH. Large, fixed-wing, military or commercial airplanes support the movement from the APOE to the SH.

3.2.1.4. Discrete-Event Simulation-Specific Definitions

1. System – is a group of objects that are joined together in some regular interaction or interdependence toward the mission. The NEO system is explained in the description above and in Figure A1 and A2 as processes in the NEO's critical path and also in A3 – A15 that capture each process as a basic queueing system (see Appendix A).
2. Entities – are the objects of interest within the system. The only entity is an evacuee. The term entity and evacuee is used interchangeably.
3. Attributes – are local properties of entities. The model is set up to assign entity attributes to include (a) whether the evacuee has pets; (b) whether the evacuee is

injured; (c) how much time on average it takes the evacuee to load a transportation medium; (d) what his/her major evacuee class or category is as described in Figure 6 below; (e) whether the evacuee will be interviewed in the ECC and (f) whether the evacuee will be detained at the ECC. Detainees are only allowed to be pulled from the population of interviewees.

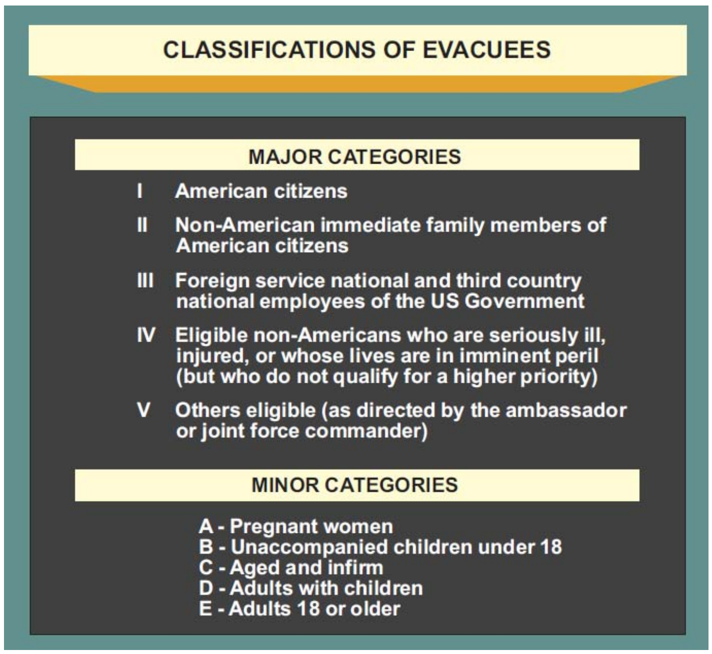

Figure 6. Evacuee Classifications   (JP 3-68, 2007: VI-10)

4. Resources – are scarce objects needed by the system. Table 3 below shows all the limited resources needed for the entire NEO system. If the resource was required to adhere to a schedule, then the name of the schedule is listed. Otherwise, all other resources are assumed available 24-hours per day. All resources are seized by individual or batched groups of entities; these resources either take the entity to the end of a travel route or the end of a process. The "Number Available" column in Table 3 is the total number of that resource available, but not necessarily the total number of resources that can be seized at a time. If a

resource is governed by a schedule, then the schedule can further limit the capacity by dictating how many of the resource can work during any certain time period. However a schedule should not allow a capacity higher than the number of resources available. Each baseline and the additional ECC schedules are defined in Table 4 and Table 5 respectively. These are in no way an exhaustive list of possibilities for scheduled resources rather those developed thus far. These tables list the times when the resource can start working, "Begin Time", the times when the resource must quit working, "End Time", and the schedule "Rule"[9].

For example, to complete the ECC process, an evacuee needs to be serviced by either a fast or slow ECC server as shown on rows one and two of Table 3. Both of these servers work according to the DoS_12 schedule for the baseline model as defined on rows one and two of Table 4. If EUCOM wishes to explore the possibility of the ECC servers working longer schedules, then the fast and slow ECC servers can work according to the DoS_16 or DoS_20 schedule as defined in Table 5. For the remaining rows of Table 3; these are other servers that serve evacuees at each of the transportation processing segments or transportation mediums that move evacuees to the different NEO locations. Finally, the ship and airplane resources also work according to schedules – respectively the port and airport schedules. As mentioned, the times and capacity for these schedules can be adjusted; Table 4 simply presents what is used for the baseline model.

[9] The schedule rule tells the simulation software what to do when an entity is still seizing a resource when it is time for the resource to stop working. In Arena, the *wait* option "will wait until the in-process entities release their units of the resource before starting the actual capacity decrease; thus, the reduced capacity time will always be of the specified duration, but the time between these reductions may increase" (Kelton et al., 2007: 135).

Table 3. NEO System Baseline Model Resources

Baseline Model - Resources					
Resources	Schedule-Based	Used By	From	To	No. Avail.
Fast ECC Servers	DoS_12	Evacuees	ECC Begin	ECC End	2
Slow ECC Servers	DoS_12	Evacuees	ECC Begin	ECC End	2
Processing Stations (Assign Travel to SPOE)	No	Evacuees	SPOE Process Begin	SPOE Process End	6
Number of ECC Land Transports	No	Evacuees	ECC	SPOE	6
Processing Stations (Assign Travel to TSH)	No	Evacuees	TSH Process Begin	TSH Process End	4
Number of SPOE (Sea) Transports	Port Schedule	Evacuees	SPOE	TSH	4
Processing Stations (Assign Travel to APOE)	No	Evacuees	APOE Process Begin	APOE Process End	6
Number of TSH Land Transports	No	Evacuees	TSH	APOE	6
Processing Stations (Assign Travel to SH)	No	Evacuees	SH Process Begin	SH Process End	4
Number of APOE (Air) Transports	Airport Schedule	Evacuees	APOE	SH	4

Table 4. NEO System Baseline Resource Schedule

Baseline Model - Schedule					
Schedule	Used By (Resource)	Begin Time	End Time	Capacity	Rule
Department of State - 12 hour day (DoS_12)	Fast ECC Servers	0600	1800	2	Wait
Department of State - 12 hour day (DoS_12)	Slow ECC Servers	0600	1800	2	Wait
Port Schedule	Seacraft	0600	2300	3	Wait
Airport Schedule	Aircraft	0400	2400	4	Wait

Table 5. NEO System Additional ECC Schedules

Additional Available Schedules					
Schedule	Used By (Resource)	Begin Time	End Time	Capacity	Rule
Department of State - 16 hour day (DoS_16)	Fast ECC Servers	0400	2000	2	Wait
Department of State - 16 hour day (DoS_16)	Slow ECC Servers	0400	2000	2	Wait
Department of State - 20 hour day (DoS_20)	Fast ECC Servers	0200	2200	2	Wait
Department of State - 20 hour day (DoS_20)	Slow ECC Servers	0200	2200	2	Wait

5. Activity – is a time period of specified length. The activities for the NEO system will all be service processes of either a preset length (deterministic) or of a random length drawn from a certain probability distribution (stochastic). Each of the essential activities is listed in Tables 6 (stochastic) and 7 (deterministic). Each table shows what process the activity is representing, "Process"; who is being served, "Customer"; what resource is doing the work, "Server"; where the service takes place, "Service Mechanism"; in how many places this service

exists, "No. of Service of Facilities"; how many servers are available at each facility, "Parallel Service Channels"; the service rate for each activity, "Service Time Distribution" or "Service Time"; and the service rate time unit, "Units". The random number stream column will be explained in Appendix C. The Fast and Slow ECC service times were based on the previous NEO data that an ECC could process approximately 100 evacuees in an hour. Based on this linear equation, the Fast ECC distribution is set to process 100 to 120 evacuees per hour and the Slow ECC distribution is set to process 80 to 100 evacuees per hour. Since the APOE Receiving process contains a lesser subset of processes than the ECC, its service rate distribution was set to be quicker than the ECC at 150 to 200 persons per hour. For the activity of traveling to the TSH and SH; no set input data was provided; so these travel times were set to a uniform distribution with the ranges of 150 ± 90 minutes and 3.0 ± 0.5 hours respectively. The time to process through each of the four processing queues for transportation was kept the same for consistency and set to 5 minutes as an educated approximation. Land travel times were set to the exact time to travel a constant distance at a constant speed; these constants are listed in Table 8.

Table 6. NEO System Stochastic Activities

Baseline Model - Stochastic Service Times								
Process	Customer	Server	Service Mechanism	No. of Service Facilities	Parallel Service Channels	Service Time Distribution	Units	Random No. Stream
Fast ECC Process	Evacuee	ECC Personnel	ECC	2	2	Uniform (0.5, 0.6)	mins	7
Slow ECC Process	Evacuee	ECC Personnel	ECC	2	2	Uniform (0.6, 0.75)	mins	8
Transportation from SPOE to TSH	Ship	Sea Lane	Sea Port	Infinite	4	Uniform (60, 240)	mins	9
APOE Receiving Process	Evacuee	-	-	1	∞	Uniform (0.3, 0.4)	mins	10
Transportation from APOE to SH	Airplane	Air Route	Airport	Infinite	4	Uniform (2.5, 3.5)	hrs	11

Table 7. NEO System Deterministic Activities

Baseline Model - Deterministic Service Times							
Process	Customer	Server	Service Mechanism	No. of Service Facilities	Parallel Service Channels	Service Time	Units
Processing Queue for Trans to SPOE	Evacuee	NEO Personnel	Processing Line	1	6	5	mins
Transportation from ECC to SPOE	Land Vehicle	Road Route	Vehicle Depot	1	6	Distance*Speed	hrs
Processing Queue for Trans to TSH	Evacuee	NEO Personnel	Processing Line	1	4	5	mins
Processing Queue for Trans to APOE	Evacuee	NEO Personnel	Processing Line	1	6	5	mins
Transportation from TSH to APOE	Land Vehicle	Road Route	Vehicle Depot	1	6	Distance*Speed	hrs
Processing Queue for Trans to SH	Evacuee	NEO Personnel	Processing Line	1	4	5	mins

6. Event – is an instantaneous occurrence that changes the state of the system. There are innumerable events in this NEO system; some examples include evacuee arrival to assembly point, evacuee arrival to ECC, departure of land vehicle from ECC to SPOE, etc …. They can be generalized as an evacuee arrival or departure, a transportation medium arrival or departure, or a process or sub-process beginning or ending.
7. Queues - are the representations that an entity can't continue along the critical path because the resource(s) it needs to complete a process are already occupied (i.e., busy or unavailable). Thus, an entity must wait in a queue for the resource.
8. Statistical Accumulators – are calculations from the simulation model that are either needed to compute a measure of performance/effectiveness (MOP/MOE) or are the MOP/MOE. For this model, statistics are needed for the verification, validation, and analysis portions of the study and will be detailed under those sections of this chapter.

3.2.1.5. Arena®-Specific Definitions

Table 8 defines all the constant variables needed in the explanation of the basic NEO system in section 3.2.1.7. The details of how to reproduce each part of the Arena® model is left for section 3.2.2.4 and Appendix C. Some the included variables will be changed during the sensitivity and scenario analyses to continue to characterize the system.

Table 8. NEO System Baseline Constant Variable Settings

Baseline Model - Constant Variable Values				
Variable Description	Variable Name	Value	Units	Value Meaning
NEO Order from Dept of State	AmbOrderNEO	1		TRUE
Entities Per Arrival	EntitiesPerArr	100	evacuees	
Maximum Arrivals	MaxArr	200		
Total Evacuees	TotalEvacuees	20000	evacuees	
First Entity Creation Time		21600	seconds	Day 1 @ 0600
Capacity at Temporary Safe Haven	TSHCapacity	2000	evacuees	10% of Total Evacuees
Number of Fast ECC Servers	FastECCServer (Resource)	2	ECC servers	
Number of Slow ECC Servers	SlowECCServer (Resource)	2	ECC servers	
Processing Stations for trvl (ECC to SPOE)	TransQStnsECCSPOE (Resource)	6	stations	
Service Time for each Transportation Processing Queue	DetProcessTime	2	minutes	
Delay Time to Waiting for Transportation	DetWaitingTime	5	minutes	
Transportation Capacity (ECC to SPOE)	TransCap_ECCSPOE	45	evacuees	Max # of evacuees per vehicle
Transportation Capacity w/ pets (ECC to SPOE)	TransCap_ECCSPOE_Pets	30	evacuees	Max # of evacuees per vehicle
ECC to SPOE Distance	ECCSPOEDistance	5	miles	
Average Land Vehicle Speed	AvgLandTransSpeedmph	20	mph	
Number Vehicles (ECC to SPOE)	LandTrans (Resource)	6	vehicles	
Processing Stations for trvl (SPOE to TSH)	TransQStnsSPOETSH (Resource)	4	stations	
Transportation Capacity (SPOE to TSH)	TransCap_SPOETSH	150	evacuees	Max # of evacuees per ship
Number of Transportation Platforms (SPOE to TSH)	AirSeaTranstoTSH	4	ships	
Processing Stations for trvl (TSH to APOE)	TransQStnsTSH (Resource)	4	stations	
Number Vehicles (TSH to APOE)	TSHLandTrans (Resource)	6	vehicles	
Transportation Capacity (TSH to APOE)	TransCapTSHAPOE	45	evacuees	Max # of evacuees per vehicle
TSH to APOE Distance	TSHAPOEDistance	10	miles	
Processing Stations for trvl (APOE to SH)	TransQStnsAPOESH (Resource)	4	stations	
Number of Transportation Platforms (APOE to SH)	AirSeaTranstoSH	4	airplanes	
Transportation Capacity (APOE to SH)	TransCapAPOESH	200	evacuees	Max # of evacuees per plane

3.2.1.6. General Definitions and Terms

Evacuation Policy – is the predicted way the resident population will respond to an evacuation order; it used to define the interarrival times distribution. There are three policies explained below. The probability density functions for each policy when it follows the 12-hour schedule is shown in Figures 7 – 9; each graph has the probability displayed on the y-axis and time in seconds on the x-axis. The distributions for each schedule (e.g. 12-, 18-, and 20-hour) and each policy are in Table 9. For policy A and C, the evacuees arrive at the ECC registration station at a time of their choosing; for policy B, the evacuees report according to a directed flow. The goal for these polices is to ensure that the entities start and stop arriving based on the start and end times of the ECC schedule given that all evacuees arrive in one day. So, the first entity creation time is the same time that the ECC opens and the distribution is set based on the average time of the last entity arrival. For instance under the evacuation policy of complacent delay (row 1 of Table 9), the ECC schedule allows for a 12-hour day thus the desired time for the all evacuees to arrive is at the 18 hour mark (ECC opening time (0600) + ECC scheduled work hours (12) = ECC closing time (1800)). To ensure these statements hold for all evacuation policies and ECC schedules, distributions following the policy's delineation below were run with 20 replications until the evacuees' total arrival time was within ± 0.1of the "desired value." Further, in order to increase the total number of evacuees, changing the "EntitiesPerArr" instead of the "MaxArr" variable allows these distributions to hold for any number of evacuees.

Policy A: *Complacent Delay* is the situation where the evacuees tend to wait until the last moment to go the assembly area. This is based on the experience of recent NEOs where the DoS paid for evacuees' travel costs. This policy employs the triangular distribution where the mode is 80 percent of the maximum. Figure 7 displays the right-skewed distribution which exemplifies the majority of arrivals later on in the allotted arrival time.

Policy B: *Structured* is the situation where the evacuees have to follow a given reporting time – most likely passed through the Warden System. In this case the DoS has split up the report times to ensure a consistent evacuee flow at the assembly point. This policy employs the uniform distribution in Figure 8 and exemplifies an equal amount of arrivals throughout the allotted arrival time.

Policy C: *Mad Rush* is the situation where the evacuees emulate a panicked crowd and arrive at the assembly point very early in the reporting time frame. This policy employs the triangular distribution where the mode is 20 percent of the maximum producing the left-skewed distribution in Figure 9 thus, exemplifying most of the arrivals early on in the allotted arrival time through the graph.

Table 9. Baseline Evacuee Interarrival Times Distributions

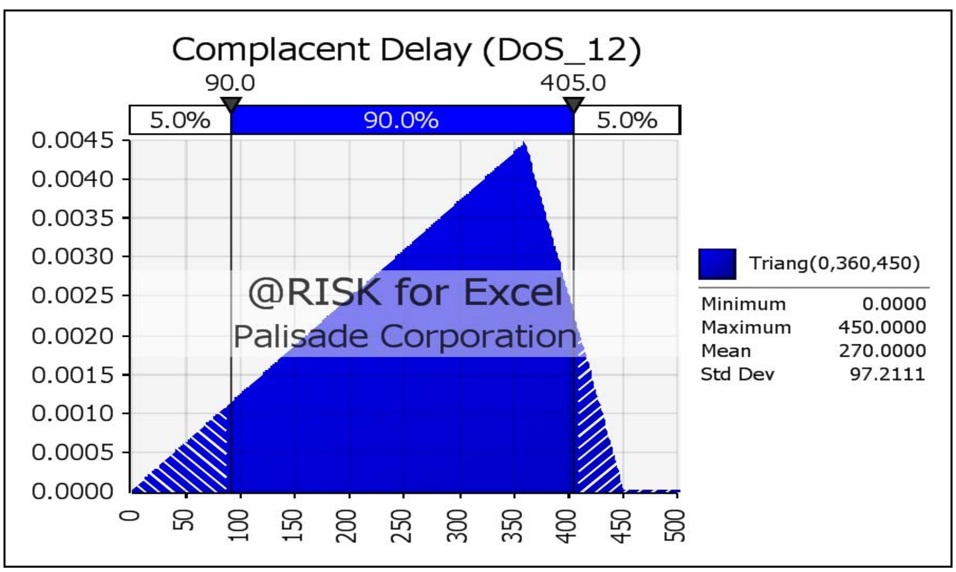

Figure 7. 12-Hour Complacent Delay Interarrival Distribution

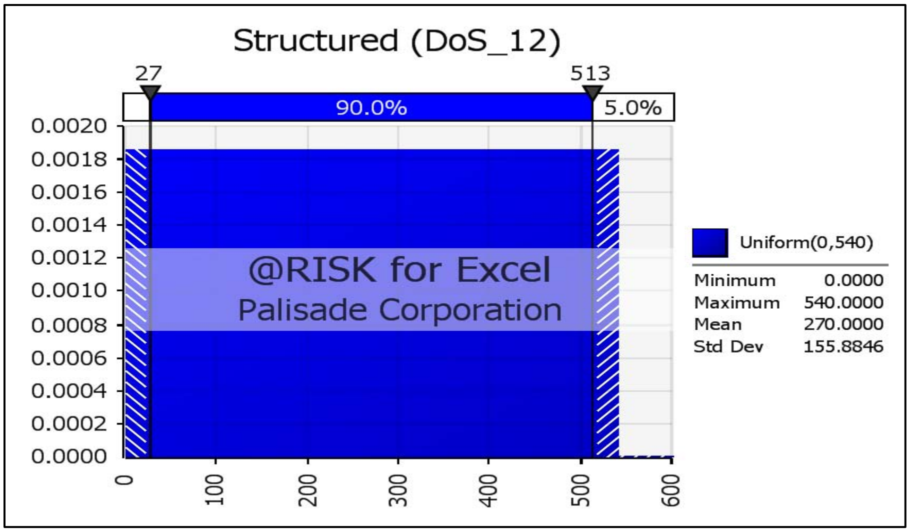

Figure 8. 12-Hour Structured Interarrival Distribution

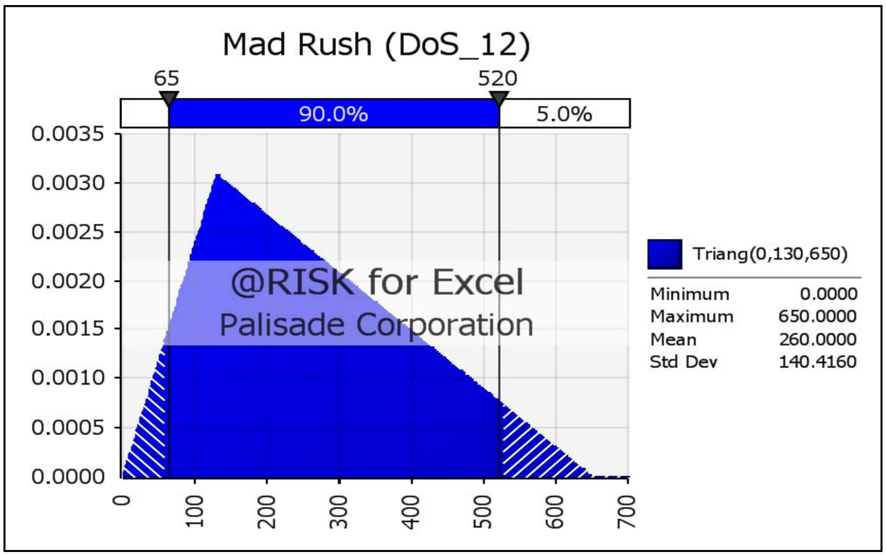

Figure 9. 12-Hour Mad Rush Interarrival Distribution

3.2.1.7. NEO System Baseline Process Description

Twenty-thousand evacuees arrive at the assembly point and immediately flow into the one of the ECCs. The evacuee decides which line to enter based on the length of each ECC's line. If the ECCs are closed based on their schedule, the evacuees simply wait until the ECCs are open again. After the evacuee completes the ECC process, it continues onto the ECC to SPOE transportation processing queue and then awaits the land transportation. The evacuee then must be batched up in groups equal to the capacity of the ECC to SPOE land transportation medium, "TransCap_ECCSPOE" and "TransCap_ECCSPOE_Pets". There are six batching lines; each of which has an equal chance of being picked for a given evacuee. These lines represent the number of existing transportation processing stations, "TransQStnsECCSPOE". For one of these lines, the capacity is 30 instead of 45 evacuees which represent evacuees who have pets which would take up about 33 percent more space than a regular evacuee. The evacuees wait in the batching area, "ECCLoad*N*", until they meet capacity.

Next the land vehicle waits to be served by the road route in the process, "OrigLandTrans*N*". Since land vehicles are limited to six in number, only six land vehicles can be on the road route at any one time. This trip is calculated using the average vehicle speed of, "AvgLandTansSpeedmph" equal to 20 mph, and the distance from the ECC and SPOE, "ECCSPOEDistance" equal to 5 miles. Thus all trips take 15 minutes. After the land vehicles arrive at the SPOE, each load is separated back to the original number of evacuees with all their original attributes. Again, the evacuee continues onto the SPOE to TSH transportation processing queue, "ProcessTransQueue_2" and then awaits the deterministic wait for transportation, "AwaitTrans_2".

At this point, the model must make sure that the TSH can accommodate another evacuee. A decision node, "Room@TSH", sums all the queues on the TSH and only allows the evacuee to continue if that sum is less than ninety-five percent of the TSH capacity. If that condition is not true, then the evacuee goes to holding area still on the HN – called "NeedForTSHOverFlow." This is most likely somewhere on the SPOE, and the evacuee waits until that condition becomes true. If that condition is true, then the evacuee goes to be batched up for the travel from the SPOE to the TSH.

This travel leg is also split up in the number of existing transportation processing stations. For this leg, the number of stations is four; thus each evacuee has an equal chance of being sent to one of the four lines. Here the evacuees are batched at each "SPOELoad*N*" into groups of 150 persons, "TransCap_SPOETSH". Once that capacity is reached, the ship awaits an available spot at the port. Since the port is only open during the defined schedule, "Port Schedule", the ships have to wait until it is open. There are three port spots and sea lanes available for simultaneous use by the ships. After the ships arrive at the TSH, the travelers then separate into the original number of entities and continue to flow through the system to the APOE transportation queue, "ProcessTransQueue_3".

Since the TSH is a source of great uncertainty for the planners and of great interest to characterize, the flow is halted at the representative TSH holding area called "ReceiveTSH". Having already accomplished the APOE transportation processing procedure, the time spent at "ReceiveTSH" represents both the TSH processing (similar to ECC processing) and the expected wait to finalize the NEO system that gets the evacuees off the TSH to the SH. The evacuees are held at the TSH as long as there are no available SH transports, "AirSeaTranstoSH", which are airplanes in this scenario. Once three or less airplanes are being used, the evacuees are released from the TSH hold.

Once released, the evacuee goes to the deterministic transportation process waiting time, "AwaitTrans_3", and then is batched for the land travel from the TSH to the APOE. This section works exactly like the land travel from the ECC to SPOE.

Number of processing stations and main transport medium capacity is also the same. However, this section doesn't segregate between evacuees who are traveling with pets as the example in the ECC land travel was just a proof of concept for EUCOM planners After the evacuees are separated back into individuals, they flow into the "ReceiveAPOE" process. As mentioned early, this represents a similar but reduced form of the ECC and evacuees are delayed for a shorter rate than at the original ECC. Note that no servers are represented for this activity; the evacuees simply experience a random delay to simulate this processing time.

For the final set of processes, the evacuees enter the fourth transportation processing queue, "ProcessTransQueue_4", and then go to the "AwaitTrans_4" constant delay. This processing station leads to four possible queues to batch for travel to the SH. An evacuee has an equal chance of being selected to enter any of the four queues. The evacuees are batched to 200, "TransCapAPOESH", and then each of four airplanes waits for the airport to be available. Since the maximum on ground (MOG) is four, all airplanes can operate simultaneously to relocate evacuees to the final point in the system.

3.2.2. Assumptions

3.2.2.1. Queueing Theory-Specific Assumptions

1. Due to the dire situations that compel the DoS to order a NEO, it is assumed that the customers (i.e. the evacuees) who travel to or arrive at the assembly area will not be dissuaded by how many other customers are already there. In other words, there is no balking.
2. Since the arrival rate of customers is not affected by the number of customers already in the system and in order to be in agreement with queueing theory, the

calling population is assumed to be infinite as a large finite number. Recall that the calling population is the potential number of customers that an input source could create.

3. All queue lengths, except for those associated with the TSH, are allowed to achieve an infinite length.
4. Since all the facility layouts are unknown and are assumed to change from NEO to NEO based on the space allotted for the operation, the facility layouts are assumed to be such that the layout is not interfering with the queue's efficiency.
5. Based on EUCOM inputs, the largest number that we need to consider for the input source is 100,000 customers. Unfortunately, given all other assumptions and model formulation, Arena® is only able to create just over 33,000 entities for a simulation; thus the most evacuees the model can currently process is 30,000. The number produced by the input source is the product of the "MaxArr" and "EntitiesPerArr" variables.

3.2.2.2. NEO System-Specific Assumptions

Each ECC has one server who accomplishes the service for all the stations (baggage inspection, reception, registration, medical care, interview, and detainment if necessary) in order to process the evacuee through the ECC subsystem. The Fast ECC server represents either a VIP or general line as shown in Figure A2 in Appendix A. Of note is that these lines have fewer stations. Other explanations for the faster processing time could include but are not limited to more experienced personnel, better processes, better flow set-ups, better processing resources (e.g., automated forms, faster network connections, more laptops, etc), more readily-accessed resources or any combination of the previous. The Slow ECC server represents the interview line where there are more stations. Conversely, the servers could be unfamiliar with the duties, the processes could be inefficient and/or the flow confusing as reasons for the slower processing times. The ECC is a key subsystem whose variance due to its various internal processes should be investigated. Unfortunately, with all the existing uncertainty in the other higher-level processes and the uncertainty with all ECC processes, the ECC cannot be fully investigated without additional input data.

3.2.2.3. Baseline-Scenario Specific Assumptions

1. NEO operational environment is permissive. This implies no impending security threat. U.S. forces can concentrate on evacuating persons with the help of the HN government without resistance to the evacuation IAW JP 3-68 (2007).
2. Joint task force fully establishes the ECC before any evacuees are processed.
3. No entities are created until ECC servers are available.
4. All entities are created on the first day within the ECC schedule working hours.
5. All entities and resources not constrained by a scheduled will move or work 24-hours per day.
6. Model completion time doesn’t include time to deploy forces and set up the ECC.
7. U.S. will be one of the last major world countries to perform a NEO to evacuate – if not the last to act. This implies that some potential evacuees for the U.S. NEO left earlier with an allying country, thus reducing the total number required to evacuate. Also, most if not all of the opportunistic resources in the HN and surrounding area will have been used by the previously evacuating countries. Thus, U.S. will have to relying its self-contained (e.g. DoS, DoD, etc.) resources.

3.2.2.4. Simulation-Related Assumptions

The following statements explain how the basic execution of the model as a simulation is done and what is assumed by making inferences from their results. Each of the runs of this model consists of 20 replications. Thus, when the model is ‘run’, there were 20 replications produced at those factor levels. The number of replications as 20 was not determined by a sample size calculation. Rather based on the consistency of the output data since all stochastic events are generated using random number streams and the advice of Dr. Miller, AFIT’s resident simulation expert; 20 to 25 replications were recommended to meet the normality assumptions implied by the software’s output data. Twenty replications were chosen due to the time each takes to complete and the time frame of this research project. (Arena® uses the following t-distribution test statistic to compute its confidence interval, $t_{(n-1,\ 1-\alpha/2)}$ in the equation for the confidence interval half width equal to $t * (s/\sqrt{n})$ where the default for the level of significance (α) is 0.05.)

3.3. Simulation Study Steps

3.3.1. Phase I: 1. Problem Formulation

Using the problem statement from Chapter 1, this simulation is a dynamic model that captures the uncertainty in a NEO system. In doing so, the simulation replicates a general or universal NEO structure with flexible inputs to account for different variable values. Finally, the simulation’s flexibility should also make the NEO system transparent such that its inner workings are readily apparent.

3.3.2. Phase I: 2. Set Objectives and Project Plan

The three objectives for the model are (1) to be able to improve crisis action planner’s insight into building better CONPLANs and OPLANs; (2) to be able to identify chokepoints or bottlenecks, flow limiters, and options to quicken queues within the NEO system; and (3) to be able to identify resources and transportation modes that display the most sensitivity with respect to time. Additionally, the project plan includes better describing the general NEO system, and thus, increasing understanding of a NEO system. The most impact this research could afford involves enhancing the ability of EUCOM/J3 to allocate command resources more effectively and identifying issues in which to concentrate diplomatic/political efforts.

3.3.3. Phase II: 3. Build Model

The model was built by using the above baseline scenario, baseline variable settings, definitions and assumptions from queueing theory and NEO joint doctrine, and the sponsor's indicated interest areas and trouble spots mentioned in the scope and assumptions from Chapter 1. The basic flow follows the model conceptualization found in A1 in Appendix A. As mentioned earlier the ECC was not broken into sub-processes. Yet, all other shaded processes in Figure A1 are broken down into sub-processes.

3.3.4. Phase II: 4. Data Collection

Since a NEO is such an acute operation, its time span makes data collection – especially in-depth endeavors -- difficult. The only available command-generated data pertains to the input source size, the ECC processing time and some of the travel legs distances and capacities. As given in the definitions, the F-77 report gives a rough estimate of possible evacuees. For this research the range suggested was between 20,000 and 100,000 evacuees. Next, from a previous NEO; the out brief from DoS personnel noted the ECC could process approximately 100 evacuees an hour or six tenths of a minute per evacuee. Since this rate was supplied with the caveat that it was a rough estimate, two processing distributions were developed on both sides of this estimate. Explicitly, these distributions are attributed to fast and slow ECC servers which are described in section 3.2.2.2. and as activities in section 3.2.1.4. The exact distributions are shown in Table 6 as between 30 and 36 seconds for the fast ECC server to process one evacuee and between 36 and 45 seconds for the slow one to do the same. The rest of the available data are planning inputs from the various components. Land vehicles' capacity is assumed by planners to be 45 persons, and the ship's capacity is contingent on several fleet configuration factors, so 150 persons is picked as the most limiting capacity of the two most common transportation mediums (e.g., Landing Craft Air Cushion (LCAC) and Landing Craft, Utility (LCU)) possibilities whose capacities are 150 and 350 respectively. The port's hours are given as 0600 – 2300. For travel to the TSH, subject matter experts expressed that actual travel time is subject to environmental considerations and conditions; thus even though approximate travel times are available, the process is an excellent candidate for being modeled as a stochastic process. For travel to the SH, the airplane's capacity is set at 200 persons. Last, the airport at the TSH is assumed to be able to handle about 24 flights a day between four airplanes and is open from 0400 to 2400.

3.3.5. Phase II: 5. Model Translation

As stated previously, model translation deals with taking the conceptualization of the system and implementing each piece in the chosen software. Taking the model concept as shown in Appendix A along with the layout shown in Figures B1 –B13 in Appendix B developed the baseline Arena® model. The following summary gives the general description of how the concept for the NEO system was translated into a computer simulation using the Arena® software. A detailed itemization of what each module does to simulate the system is left to Appendix C.

Using the modules from Arena's Basic Processes and Advanced Processes panels, the evacuees are created and then moved through the series of processes as described in section 3.2.1.7. In general the transportation processes (i.e., the acts of actual travel) are set up as queueing systems with only one parallel server per system where as the ECC and the processing stations in-between travel legs are set to have multiple parallel servers. If an evacuee needs to be served, then that service is represented by the "process" module and is set to either a "delay" (i.e., no defined server or resources required) or "seize delay release" (i.e., a server or resource is seized for a certain time delay and then released when the evacuee's service is complete) option. Each of these process–to-server relationships is detailed in Tables 3, 6 and 7. Moreover, the "decide" and "hold" modules perform any logic that the system required for either when the NEO system has more than one option or if access to the next process may be contingent on a certain condition. For the segments where travel is accomplished, the evacuees are batched into capacities appropriate for the transportation medium and then separated back into individual entities after the travel is complete. As a note, to replicate the dwindling down of evacuees as the operation nears its end, the capacities are changed to smaller values for the last 0.05 percent of evacuees given 20,000 total evacuees.

The remaining modules are used to provide input variables for the modules discussed above or to provide data and/or statistics such that the model could be verified, validated, and analyzed. The "assign" modules assign a new value to any variable, attribute, etc. using the provided definition. Thus, if the variable, attribute, etc. had an initial value when the simulation began that value will be replaced with an updated value every time an entity goes through that “assign” module. Likewise, if a variable had no initial value of consequence, its value would be still be updated for as many times as an entities goes through the module. The “record” modules will perform some sort of calculation, such as count by adding one, each time an entity goes through the module. Finally, the “readwrite” module is used several times to send data to text files such that the outputs are more easily manipulated for analysis.

3.3.6. Phase II: 6. Model Verification

The two main methods used for verification of this simulation were comparison to input data and use of Arena®’s animation feature. With animation, the flow, order and actions of the evacuees could be verified as they move through each part of the NEO system. Animation also verified that the resources governed by a schedule were stopping and starting at the appropriate times according to the different schedules. Finally, animation in conjunction with a dynamic plot of the current value of the total number in the TSH confirmed that the flow control placed before the evacuees went to the TSH was properly working. In short, if the TSH was already at ninety-five percent of its capacity then the evacuee is sent to an overflow holding area. Then, as soon as the TSH dropped below ninety-five percent of its capacity, the evacuees in the holding area were released to check for passage to the TSH again.

As far as comparisons to the input data, values were checked with respect to constant variables, number of entities through the system, number in the TSH and anticipated average service times and number of transports required. The verification of the last arrival times was previously explained in section 3.2.1.6. For the following comparisons, the data comes from 20 replications of the baseline run with settings given in Table 8. First, all constants (e.g., “DetProcessTime”, “DetWaitingTime”, “MaxArr”, “AvgLandTransSpeedmph”, “TransCap_ECCSPOE”, “TransCap_ECCSPOE_Pets” and “EntitiesPerArr”) had an average equal to their initial value with a half width of 0.00; proving that they attained and kept the correct values.

For the number of entities, the baseline creates 20,000 evacuees, but then 10 more are created to represent evacuees who ‘appear’ at points other than the expected starting point. Also, the duplicate option on several of the “separate” modules is used to clear out the batch modules so there are additional entities added via duplication. To verify that the number of entities going through the NEO system was the expected amount the variables “NumDoneECC”, “NumtoSPOE”, “NumDoneSPOE” and “NumDoneTSH” count the number of entities in the system at pivotal points in the system; particularly after entities are created and duplicated. With the operations performed (i.e., the “create” and “separate” modules used), the numbers for each should be 20,000; 20,015; 20,018; and 20,023. The reports for all baseline runs consistently confirmed those counts in the category overview report.

To reiterate its importance, the TSH and its capacity is of great concern to the EUCOM planners. To verify that the logic checking the size of the TSH to its given capacity as explained above, the values for the variable “TotalNum@TSH” were collected in a text file and graphed with respect to each entity as shown in Figures 10 - 12 below. All these figures display the actual TSH level as evacuees go through the TSH for a baseline run; thus the total number of evacuees is 20,000 people. The TSH capacity is set to 2,000; 1,000, and 500 people for Figures 10 - 12. In these figures, the number of evacuees in the TSH is on the vertical axis and the entity number (i.e., the first through the twenty-thousandth entity to go through the TSH) is on the horizontal axis. Because Figures 10 and 11 are representative of every simulation with these same settings (i.e., the baseline settings with the TSH capacity set to 2,000 and 1,000) and none of these simulations utilize the TSH overflow decision node[10], this confirms that the evacuee flow resulting from the baseline model isn't reaching the capacity until the capacity is set below 1,000 (e.g., Figure 12 where the capacity is 500). For this last setting for the TSH capacity, 775 entities are sent to this overflow.

The last major comparison areas are the average process service times and number of transports used. For the process service times, Table 10 below gives the average value added time per entity over 20 replications with its associated half width for a 95 percent confidence interval as produced in Arena®'s output report. The column on the right, "Set Avg" shows what the model's average programmed value was. By inspection of the table, the confidence interval (i.e., avg time per entity ± half width for any process that has one) contains the set average. For the first row, "APOEASTrans1" has an average time per entity and half width of 3.0113±0.02; this produces the confidence interval, (2.9913, 3.0313), which includes the expected set average of three. Finally, to check the number of transportation mediums seized, the user-defined count for each transportation type is compared to the total number of evacuees divided by the capacity of the transport. These values in Table 11 are suitable especially given the increased fluctuation in the vehicle's capacity over the course of the replication.

[10] This decision node function will be explained in Appendix C; but this node will not send entities on through the system unless the number of evacuees in the TSH is 95 percent less than its capacity.

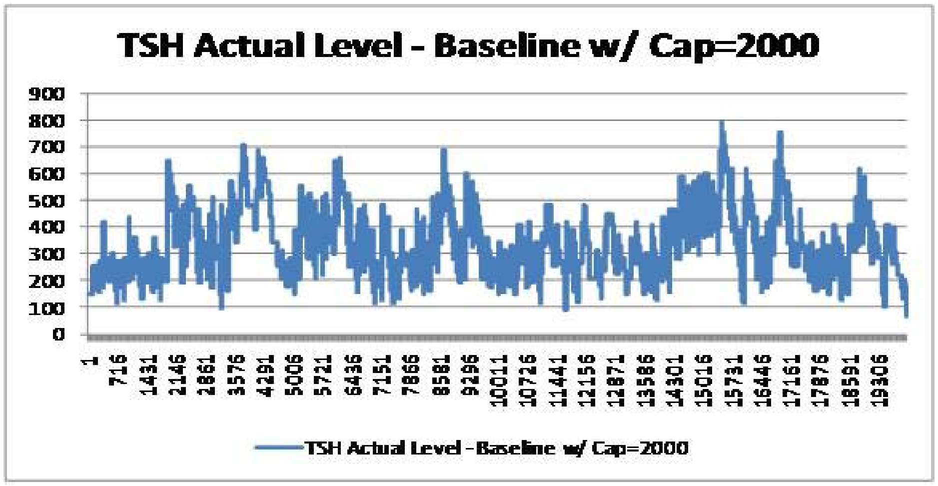

Figure 10. Baseline TSH Levels (Capacity = 2000)

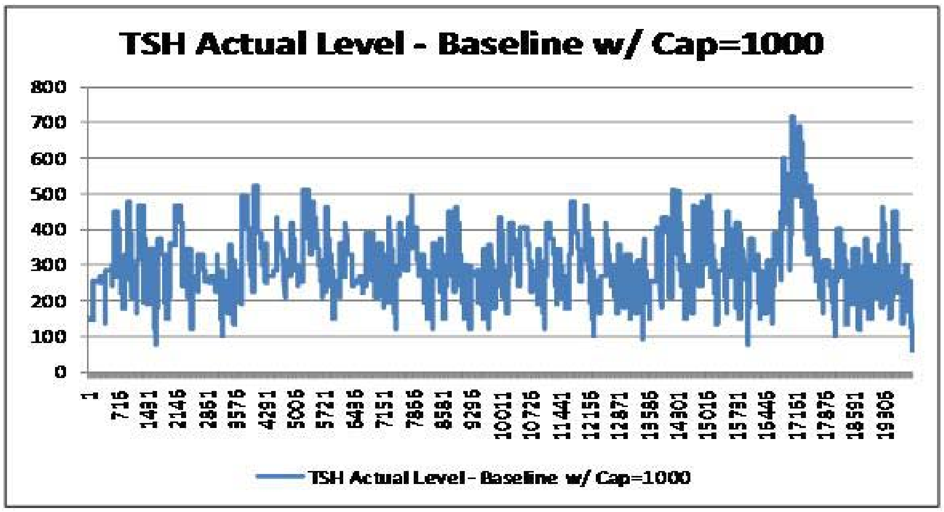

Figure 11. Baseline TSH Levels (Capacity = 1000)

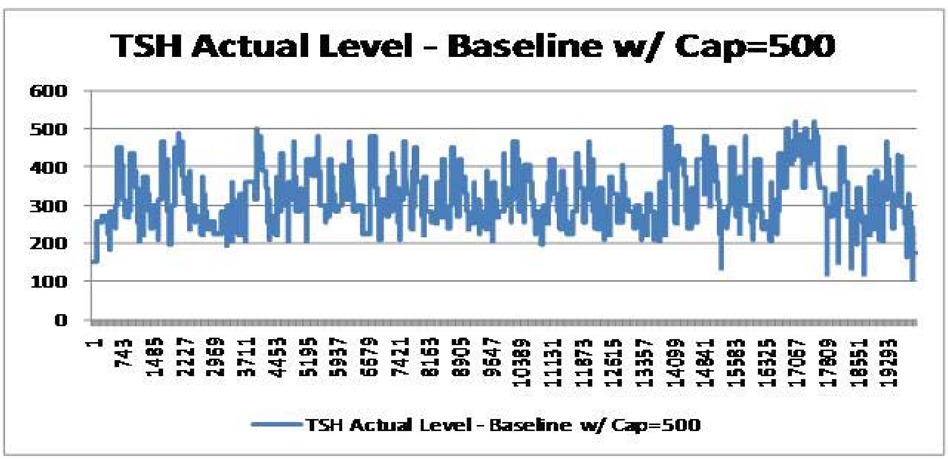

Figure 12. Baseline TSH Levels (Capacity = 500)

Table 10. Expected vs. Baseline Service Times[11]

Baseline Service Times					
Process Name	**Avg Time Per Entity**	**Units**	**Half Width**	**Set Avg**	**Units**
APOEASTrans1	3.0113	hrs	0.02	3	hrs
APOEASTrans2	2.9819	hrs	0.02	3	hrs
APOEASTrans3	2.9984	hrs	0.02	3	hrs
APOEASTrans4	2.9774	hrs	0.03	3	hrs
AwaitTrans_1	0.083	hrs	0.00	5	mins
AwaitTrans_2	0.083	hrs	0.00	5	mins
AwaitTrans_3	0.083	hrs	0.00	5	mins
AwaitTrans_4	0.083	hrs	0.00	5	mins
Fast ECC Processing	0.0092	hrs	0.00	0.009	hrs
Slow ECC Processing	0.0113	hrs	0.00	0.01125	hrs
OrigLandTrans1	0.25	hrs	-	15	mins
OrigLandTrans2	0.25	hrs	-	15	mins
OrigLandTrans3	0.25	hrs	-	15	mins
OrigLandTrans4	0.25	hrs	-	15	mins
OrigLandTrans5	0.25	hrs	-	15	mins
OrigLandTrans6	0.25	hrs	-	15	mins
ProcessTransQueue_1	0.033	hrs	-	2	mins
ProcessTransQueue_2	0.033	hrs	-	2	mins
ProcessTransQueue_3	0.033	hrs	-	2	mins
ProcessTransQueue_4	0.033	hrs	-	2	mins
Receive APOE	0.0058	hrs	0.00	0.00585	hrs
SPOEASTrans1	2.4784	hrs	0.06	2.5	hrs
SPOEASTrans2	2.5309	hrs	0.07	2.5	hrs
SPOEASTrans3	2.4882	hrs	0.07	2.5	hrs
SPOEASTrans4	2.5109	hrs	0.08	2.5	hrs
TSHLandTrans1	0.5	hrs	-	30	mins
TSHLandTrans2	0.5	hrs	-	30	mins
TSHLandTrans3	0.5	hrs	-	30	mins
TSHLandTrans4	0.5	hrs	-	30	mins
TSHLandTrans5	0.5	hrs	-	30	mins
TSHLandTrans6	0.5	hrs	-	30	mins

Table 11. Expected vs. Baseline Number of Transports Used

Baseline Transports Used			
Transportation Medium	**Set Capacity**	**Number Used**	**Expected Value**
ECC Land Vehicles	42.5*	503	470.59
AirSeaTransToTSH	150	135	133.33
TSH Land Vehicles	45	453	444.44
AirSeaTransToSH	200	103	100.00
* - This is the average of five vechicles at 45 and one at 30.			

3.3.7. Phase II: 7. Model Validation

In order to validate a simulation model, output data from the real system must be compared to the output of the simulation where the latter should be an approximation of

[11] For clarity in the comparisons in Table 10, 0.083 hours = 5 minutes; 0.25 hours = 15 minutes; and 0.033 hours = 2 minutes; 0.5 hours = 30 minutes.

the former. The only true input data provided in terms of system performance was the approximate average service time for ECC processing of 36 seconds (i.e., 100 evacuees processed per hour). This data was validated as part of the verification in that the baseline model produced an average service time of 0.0092 hours (33.12 seconds) for the fast ECC server and 0.0113 hours (40.68 seconds) for the slow ECC server which closely approximates the actual ECC service times of 0.009 hours (32.4 seconds) and 0.01125 hours (40.5 seconds) respectively. The lack of ability to fully validate the NEO model is explicitly addressed in Chapter 5 with suggested data needed and methods to gather the required data to progress the model into a validated one.

3.3.8. Phase II: 8. Use of Experimental Design

In order to show the capabilities of this model given it is able to be validated, the following experiments shown in Tables 12 – 15 were run. Tables 12 and 13 are one factor at time (OFAT) experiments which are usually not recommended in the OR field because they fail to consider any possible interaction between the factor(s) that are changing (Montgomery, 2009: 4); however, due to the user's purpose for this model, showing how the model can handle simple planning factors and target multiple performance areas is constructive. Tables 14 and 15 are based in design of experiments[12]. The power of this planned experiment method includes being able to indicate interactions that OFAT may miss and to capture the sometimes unexpected (i.e., unintuitive) results which will supplement the planner's operational experiences. Before

[12] Montgomery (2009: 11) defines statistical design of experiments as "the process of planning the experiment so that the appropriate data will be collected and analyzed by statistical methods, resulting in valid and objective conclusions."

these experiments are further explained, the MOPs analyzed in these experiments are first defined.

The following is an explanation of the six measures of performance for the NEO system as a subset of multiple performance areas are outputted in forms suitable for analysis. (1) **Evacuation Completion Time**: First, the main area of concern is the time that it takes for the evacuees to arrive at the final safe haven or the replication completion time since this is when the simulation ends (i.e., the time when the 20,000th evacuee is sent to the SH). The MOP to measure this time is the average completion time for all 20,000 evacuees to process through the NEO system, which is the average of the 20 replications' completion times. (2 – 5) **Last Time Through ECC, Last Time Through SPOE, Last Time Through TSH, Last Time Through APOE:** Next, the model logs the times as each evacuee completes a major portion of the evacuation (e.g., finishing the ECC and travel to the SPOE, TSH and APOE). Since each evacuee's time is recorded for each of these events; it is not useful to take the average of these times as the objective is to know how long it takes for all the evacuees to clear that portion of the system. Therefore, the MOP that is used is the average for 20 replications of the maximum time that the last entity finishes with that portion of the evacuation. Unless otherwise noted all times are reported in hours. (6) **Maximum Queue Lengths**: The last MOP used is the maximum length of the processes with the five longest lengths. The same five processes qualify for this MOP for all the various versions of the baseline model tested in this research and will be listed when analyzed.

The OFAT experiments investigate four different scenarios. The first scenario demonstrates the impact of the DoS personnel extending their daily schedule at the ECC from a 12-hour to 16-hour day on the evacuation completion time and last time through ECC. Next, given the bottlenecks have been accurately identified as including the transportation processing stations (i.e., the stations directly after each transportation mode), the second scenario doubles the number of servers at each of these stations and shows how this affects the completion time and last time through the TSH. If the supporting nation for the airport allows the JTF to occupy more ramp space, then, the maximum on ground MOG) number can be increased. Thus, in the third scenario, the MOG be increased from four to six aircraft and highlights the affect on completion time and last time through the APOE. On a different note, the second OFAT experiment in Table 13 considers a circumstance where the result could drive diplomatic discussions as well as force planning requirements. Given the travel from the HN to the TSH is via sea travel, the number of vessels allowed to operate is at the pleasure of the HN; thus knowing how many slips to request that would positively affect movement in evacuee flow is key knowledge. This translates to letting the capacity of the sea port range from one to five vessels and measures the effect on completion time (in days).

The two designed experiments, in Tables 14 and 15, address finding any interactions with the ECC and major NEO-system resources (i.e., ECCs, ships and planes). Focusing on the ECC, the first experiment varies the ECC servers' processing speed from fast, mixed (i.e., half of the server are fast and half slow – this is the baseline setting), to slow; the DoS personnel ECC schedule between 16- and 20-hour days; the number of ECCs (or the number of ECC servers as each ECC represents one ECC server) between two and six and the number of processing stations for the first station after the ECC as four and eight. This concentrates on the effect in the time the last evacuee left the TSH. The next test looks at the combination of two and six ECCs; three, four, and five port spaces; and four, five and six airplanes with respect to the change in average completion time. The results of the all four tests are presented in Chapter 4.

Steps 9 and 10 of this simulation study will be addressed in Chapters 4 and 5. As for Step 11, documentation and reporting, this report serves to meet the progress and program commentary requirements. Also, the implementation is addressed to some extent in Chapter 5 although the check for whether this research can be accepted by EUCOM as a credible option exceeds the timeframe of this research.

Table 12. OFAT Planning Examples

Scenario	Planning Consideration	Variable	Baseline Value	New Value	MOP
1	Convince DoS to work longer schedule	ECC Schedule	DoS_12	DoS_16	Avg Time - Last Evac Thru ECC Avg Completion Time
2	Direct Forces to Bottlenecks	Processing Stations	4, 4, 6, 6	8, 8, 12, 12	Avg Time - Last Evac Thru TSH Avg Completion Time
3	Increase in MOG	Airport Capacity	4	6	Avg Time - Last Evac Thru APOE Avg Completion Time

Table 13. OFAT for Diplomatic Justification

Diplomatic Consideration	Variable	Baseline Value	New Value	MOP
Support for # of Port Spaces	Port Schedule Capacity	3	1, 2, 4, 5	Avg Completion Time

Table 14. ECC Optimization Designed Experiment

Run	ECC Process Speed	ECC Schedule	No. of ECC	Process Stns After ECC
1	Fast	DoS_16	6	12
2	Mixed	DoS_16	2	12
3	Slow	DoS_16	2	6
4	Fast	DoS_20	2	12
5	Fast	DoS_16	2	6
6	Mixed	DoS_16	2	6
7	Slow	DoS_20	2	12
8	Mixed	DoS_20	6	12
9	Slow	DoS_16	2	12
10	Mixed	DoS_16	6	6
11	Slow	DoS_20	6	6
12	Fast	DoS_16	2	12
13	Fast	DoS_16	6	6
14	Mixed	DoS_20	6	6
15	Slow	DoS_16	6	6
16	Slow	DoS_20	2	6
17	Slow	DoS_20	6	12
18	Mixed	DoS_20	2	6
19	Slow	DoS_16	6	12
20	Mixed	DoS_20	2	12
21	Mixed	DoS_16	6	12
22	Fast	DoS_20	6	6
23	Fast	DoS_20	6	12
24	Fast	DoS_20	2	6

Table 15. Resource Optimization Designed Experiment

Run	No. of ECCs	No. of Port Spaces	No. of Planes
1	6	5	5
2	2	4	4
3	6	3	6
4	6	5	4
5	2	4	6
6	2	3	5
7	6	5	6
8	6	4	4
9	2	3	6
10	2	5	5
11	6	4	5
12	2	3	4
13	6	4	6
14	2	5	4
15	6	3	5
16	6	3	4
17	2	4	5
18	2	5	6

3.4. Summary

The main thrust of this research effort was producing a representative model followed by a statistical and sensitivity examination of the model to investigate known problem areas (in the ECC and TSH), relationships between changes in planning factors and various measures of the NEO system performance, and contingencies such as additional DoS personnel and evacuees with pets. Although the model building and verification efforts consumed most of the time available for this research project, four considerable scenarios were preformed to explore the usability and applicability to EUCOM NEO planning.

Chapter 4: Results and Analysis

4.1. Introduction

This chapter presents the resulting data from the experiments described in section 3.3.8. of Chapter 3. The following is a continuation and conclusion of Phase III of the simulation study steps. The data collected from this phase is analyzed for statistical significance and general application or trends. For each test, the met research objectives are detailed in kind in Chapter 5. Due to the time constraints, only the second designed experiment in section 4.3.1 is the result of executing additional runs. Thus for Step 10 of the simulation study process, most of the desired additional experiments are set but not executed. A crucial caveat for the results presented in this chapter is that the precise statistical values or even general knowledge gleaned about how the NEO system functions cannot be applied back to the NEO system due to the inability to fully validate the model; rather these experiments offer possible insights and applications in the planning process.

4.2. Phase III: 9. Production Runs and Analysis

4.2.1. Joint Planning Scenarios and Results

Following from the given scenarios described in Chapter 3, the results for the first three scenarios are shown in Table 16. The raw data for these results is provided in Table D1 in Appendix D. Further, the output was tested using a hypothesis test of the form below with each μ_o equal to the baseline value for that particular MOP.

H_o: $\mu = \mu_o$

H_A: $\mu \neq \mu_o$

The following statistical results were determined using the two-sided t-test with $n = 20$ and $\alpha = 0.05$ and thus a critical value of $t_{critical} = t_{1-\alpha/2,\, n-1} = 2.09$ for all comparisons. From the top row, the corresponding $t_o = (x - \mu_o)/(s - \sqrt{n})$ and s values for each point estimate in the 'New Result' column are (1a) $t_o = -133.44$, $s = 0.43$; (1b) $t_o = 0.794$, $s = 9.58$; (2a) $t_o = -3.66$, $s = 6.37$; (2b) $t_o = -0.011$, $s = 13.06$; (3a) $t_o = -0.007$ and $s = 6.37$; and (3b) $t_o = -0.011$, $s = 13.06$ with 1a and 2a rejecting the null hypothesis.

Table 16. OFAT Planning Experiment Results

Scenario	Planning Consideration	Variable	Baseline Value	New Value	MOP	Baseline Result	New Result
1a	Convince DoS to work longer schedule	ECC Schedule	DoS_12	DoS_16	Avg Time - Last Evac Thru ECC	80.22	67.39
1b					Avg Completion Time	266.99	268.69
2a	Direct Forces to Bottlenecks	Processing Stations	4, 4, 6, 6	8, 8, 12, 12	Avg Time - Last Evac Thru TSH	144.99	138.98
2b					Avg Completion Time	266.99	266.34
3a	Increase in MOG	Airport Capacity	4	6	Avg Time - Last Evac Thru APOE	142.82	142.81
3b					Avg Completion Time	266.99	266.34

As delineated in green and red, only the average of the maximum time through the ECC and the TSH were found statistically significant for the changes made in scenario one and two respectively. First, this implies that changing the number of hours that the DoS personnel work in one day from twelve to sixteen does have an effect on evacuees timing out of the ECC by decreasing the time required. Yet, this change has no effect on the evacuation completion time. Next, by doubling the number of servers at each of the processing stations, the average maximum time that it takes for all the evacuees to leave the TSH is reduced by a statistically significant amount. Again, this change has no significant affect on the average completion time. In addition, increasing the airport capacity which essentially adds two planes has no affect on the maximum average time for the evacuees to complete all parts of the NEO system through the APOE or the evacuation completion time.

These scenarios were also compared with the top five maximum queue lengths for each scenario. Incidentally, the same five queues held the maximum lengths with a significant gap between the fifth and sixth largest queue lengths. (Note: Since this is the maximum queue length over the 20 replications, there is only one data point and no statistical tests can be performed.) The five queues were for Fast ECC Processing (Fast ECC), Slow ECC Processing (Slow ECC), Process Transportation Queue 1 (PTQ_1), Process Transportation Queue 2 (PTQ_2), and Process Transportation Queue 4 (PTQ_4); the output for the baseline and three scenarios (i.e., S1, S2, and S3) are shown in Figure 13 where the vertical axis is the maximum length of the process's queue length with the corresponding process on the horizontal axis. Scenario one slightly decreases the ECC's queue length but considerably increases (by ~3,000) the queue for PTQ_1; thus this change creates a larger bottleneck further down in the evacuee flow. Scenario two has no effect on the ECC queue lengths as would be expected, since the change is made after that portion of the system, but has a significant positive effect in decreasing the remaining queue lengths. For scenario three, the change in number of aircraft continued to have no noticeable effect and in fact mirrors the baseline's queue lengths.

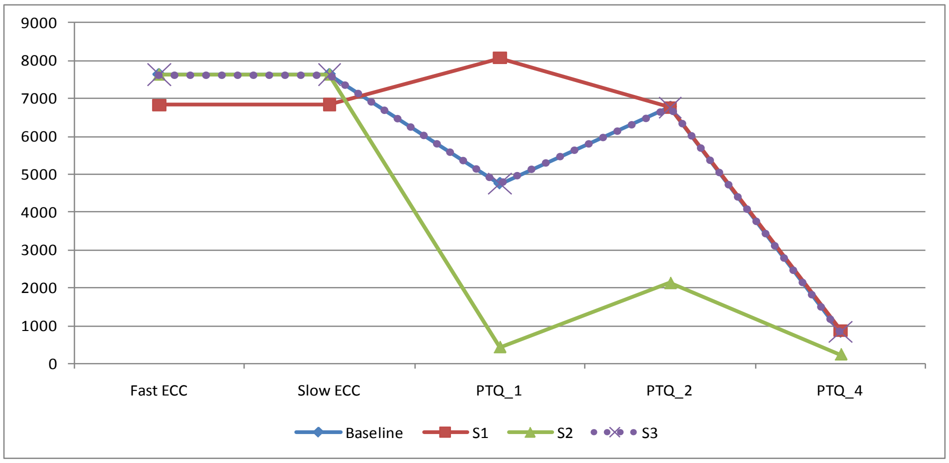

Figure 13. Comparison of Max Queue Lengths for Scenarios

4.2.2. Diplomatic Planning Scenario and Results

The next test demonstrates the extension of this model as tool to aide DoD and DoS coordination and planning efforts. For the scenario explained in Chapter 3, the results for changing the number of port spaces available from one to five are in Table 17 and 18 and Figure 14. (Figure 14 shows the average completion time in days on the vertical axis and the number of port spaces along the horizontal axis.) The graph clearly shows that the average completion time does not change significantly in the practical sense when increased from three to four or from four to five port spaces. Yet, the gain from one to two and two and three port spaces does noticeably reduce the average evacuation completion time.[13] Thus, if the goal is to reduce the evacuation time, this result provides motivation to fight for additional port spaces up to three. However the complexity of the system sets in at four and five port spaces making the trade off advantages for staking claim to these resources minimal at best.

Table 17. OFAT Diplomatic Considerations Result

Diplomatic Consideration	Variable	Baseline Value	New Value	MOP	Baseline Result	New Result
Support for # of Port Spaces	Port Schedule Capacity	3	1	Avg Completion Time (in days)	8.71	20.7
			2			11.1
			4			8.64
			5			8.65

Table 18. Factor Level Statistical Estimates

NEO Completion Time (hrs)					
	Number of Port Slips				
	1	2	3	4	5
Average	20.69	11.12	8.71	8.64	8.65
Std Dev	0.92	0.50	0.24	0.11	0.09
Avg Marginal Gain	n/a	9.563542	2.412667	0.074312	-0.013312

[13] Hypothesis test are performed as comparison to a mean as done with first set of scenarios with $\mu_o = 8.71$ as three port space is the baseline setting for this variable. The t_o values for 1, 2, 4 and 5 port spaces are 58.23, 21.56, -2.85 and -2.98. When compared the critical value of 2.09, all settings are statistically significant but the graph in Figure 14 focuses on finding the true practical improvements.

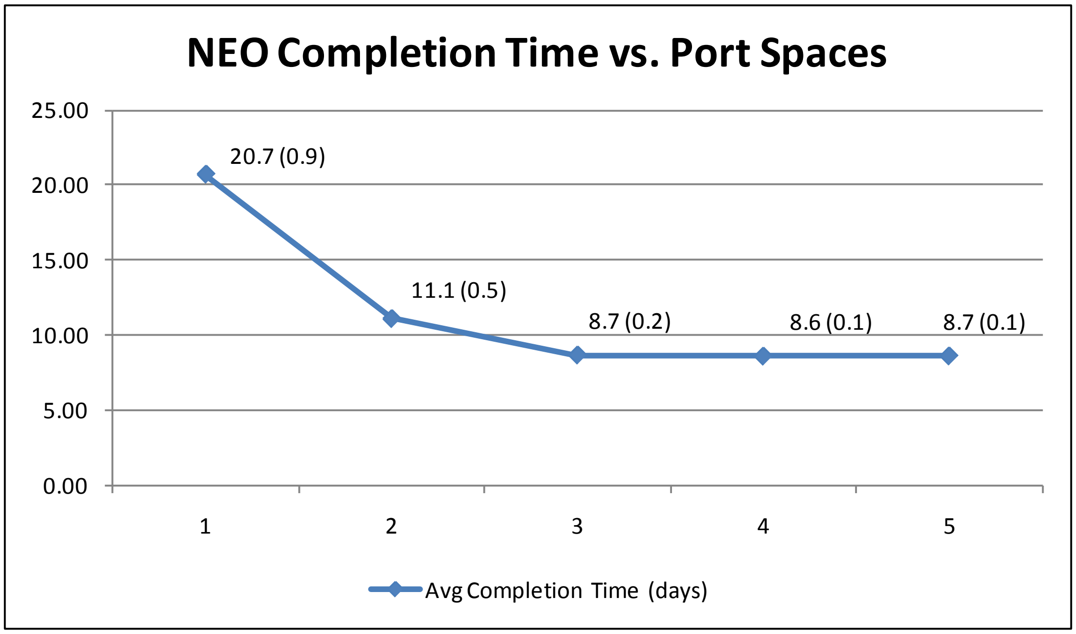

Figure 14. Decreasing Returns from Increased Port Resources

To review the points mentioned about OFAT in Chapter 3, these examples have a realistic application in the crisis action phase of planning an operation such that effects of changes in resources can be tested to determine the result of the change and also the extent of any positive or negative effect. They are also simple examples to display the range of this simulation tool's application and enumerable outputs that can be generated from the simulation model. It is recommended that experiments such as the ones that follow be used to gain a better understanding of the whole system and how its factors interact.

4.2.3. ECC Designed Experiment and Results

In this next experiment, the many variables of the ECC are explored to see what effect, if any, can be made on the time to complete the TSH portion of the evacuation. Using the factor settings explained in Chapter 3 and the data shown in Table D3 (Appendix D), the output for the response variable, maximum average of the last TSH time, is analyzed using the statistic software package, Design Expert, and analysis of variance (ANOVA) as presented in Table 19. The effects included in this model were chosen based on the half normal plot shown in Figure 15. The half normal plot graphically shows the more significant (to the model) effects based on their position according to the normal line; the significant effects are those found off the line. Thus, this model is rare in that the most significant effects are the three-level interactions and the main effects are included simply due to hierarchy. (In order to use the model produced by this analysis, certain normality and independence assumptions must be met. The graphs that show the assumptions hold are found in Appendix D for this and the next designed experiment.)

Table 19. ECC Experiment ANOVA

Response:	**MaxAvgLastTSHTime**				
ANOVA for selected factorial model					
ECC DOE Experiment					
Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F
Model	124.079	13	9.54456	6.11919	0.0035
A-ECC Process Speed	7.46718	2	3.73359	2.39367	0.1414
B-ECC Schedule	0.12042	1	0.12042	0.0772	0.7868
C-No. of ECC	0.58282	1	0.58282	0.37365	0.5547
D-TransQStns (ECC-SPOE)	0.12615	1	0.12615	0.08088	0.7819
AB	18.2739	2	9.13693	5.85785	0.0207
BC	10.0622	1	10.0622	6.45103	0.0294
ABC	31.786	2	15.893	10.1893	0.0039
ABD	33.427	2	16.7135	10.7153	0.0033
BCD	22.2338	1	22.2338	14.2545	0.0036
Residual	15.5977	10	1.55977		
Cor Total	139.677	23			

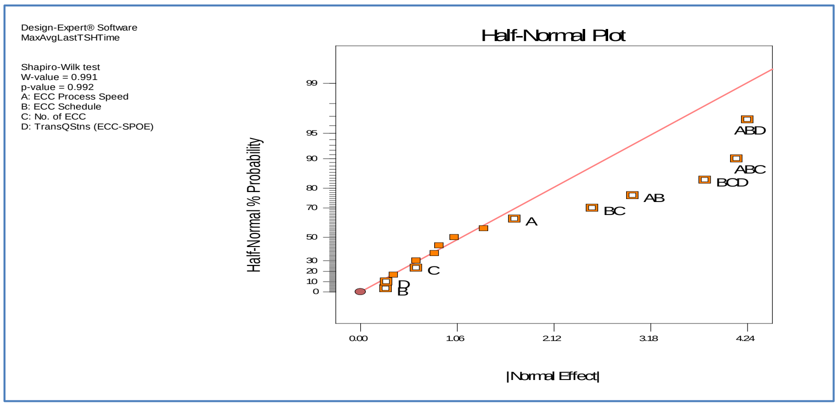

Figure 15. ECC Model Effects Half-Normal Plot

This model with the included effects is significant such that the F-value of 6.12 only has a 0.35 percent chance of getting the same results due to noise. Also, the model explains about 74 percent of the variability when adjusted for number of included effects. The fact that the highest contributors and most significant effects (i.e., the lowest p-values) are three three-level effects, ABC, ABD, and BCD suggest the relationship between these factors is extremely complex. In fact, the plot of the ABC interaction confirms that in order to get the desired understanding of the result, these plots (Figures 16 and 17) need to be scrutinized. To interpret, Figure 16 shows that the best performance in the response (i.e., lower is better) is given when the ECC schedule is equal to a 16-hour day, ECC servers speed is slow and with the average effect on the response for the two factor settings of the transportation processing stations from the ECC to SPOE. However if only the number of ECCs is changed to six as shown in Figure 17, then it is best to use the 20-hour schedule with either all Fast or all Slow ECC servers. This result is definitely not intuitive.

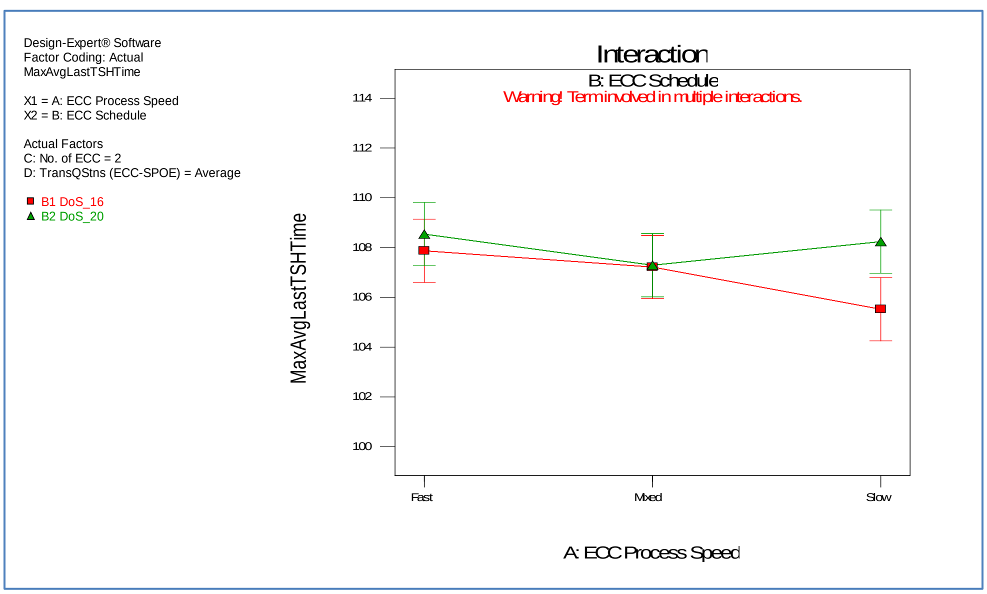

Figure 16. ABC Interaction with C = 2 ECCs

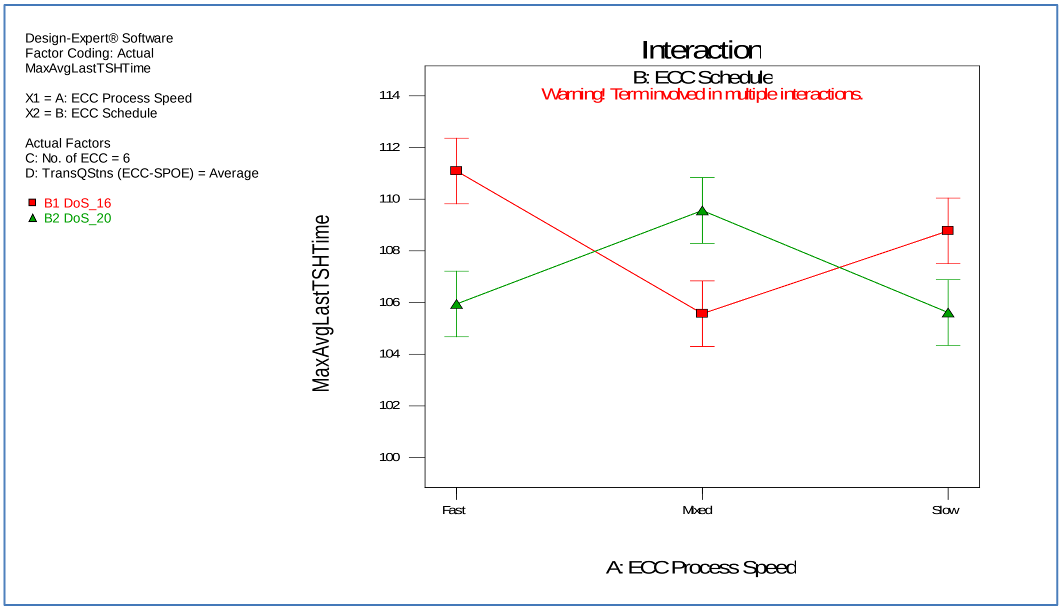

Figure 17. ABC Interaction with C = 6 ECCs

4.3. Phase III: More Runs

4.3.1. Major Resources Designed Experiment and Results

Based on the findings from the scenario regarding the number of available spaces at the port, the following experiment extends sample space and uses a full factorial design with the factors of number of port spaces, number of ECCs and number of planes each with factor levels of three, four, and five port spaces, two and six ECCs and four, five and six airplanes at the APOE. These settings produced the results on the average completion time as shown in Table D4 (Appendix D) and in the analysis of variance (ANOVA) in Table 20. The goal of this experiment is to see if any additional improvement in the NEO completion time can be gained by increasing major resource capacities. The resulting model is somewhat disappointing in that only the number of airplanes factor is significant to the model (i.e., that factor drives the response's variability); this is also shown graphical in the half-normal plot in Figure 18. This model explains only 56 percent of the variability when adjusted for the number of included treatments; this is an adequate level for the coefficient of determination but not an exceptional one (Montgomery, 2009: 97). From Figure 19, the only inference from this model is that the evacuation completion time is decreased as the number of airplanes is increased. Albeit simple, this is still an informative result. In particular assuming a valid simulation model, EUCOM planners now know that if only the number of ECCs, port spaces and airplanes could be changed from the baseline settings, they should only concentrate on getting more airplanes for the APOE to decrease the evacuation completion time.

Table 20. Resource Experiment ANOVA

ANOVA					
Response:		Avg Completion Time			
	Sum of		Mean	F	p-value
Source	Squares	df	Square	Value	Prob > F
Model	18.344967	2	9.172483	12.07001	0.0008
C-# Airplanes	18.344967	2	9.172483	12.07001	0.0008
Residual	11.399096	15	0.75994		
Cor Total	29.744063	17			

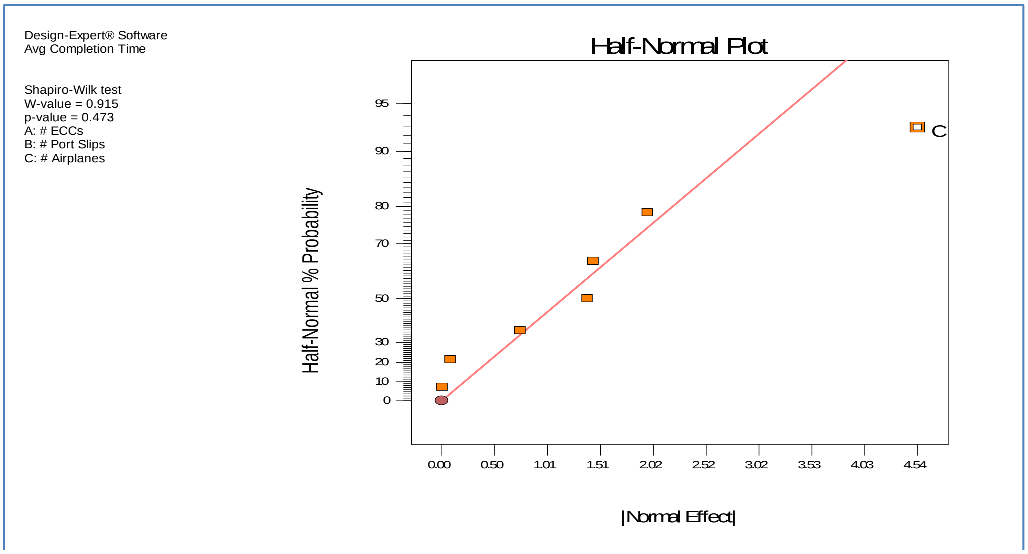

Figure 18. Resources Model Effects Half-Normal Plot

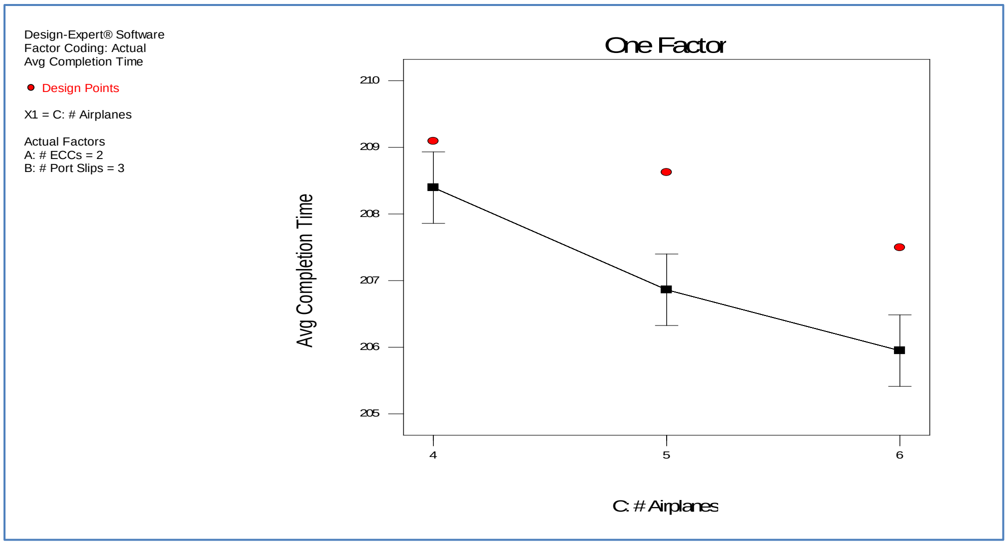

Figure 19. One Factor Plot of Number of Airplanes

Based on the results from all these experiments, the 2^9 factorial design outlined in Table 21 would incorporate the finding thus far and hope to build on understanding which system factors affect the evacuation completion time and how these affect the evacuee wait time (i.e., through the maximum queue length response). This design can be split up into fractional factorial designs using sequential experimentation[14].

Table 21. Additional Screening Experiment

Response:	**(1) Average Evacuation Completion Time and (2) Maximum Queue Length**		
Factors	**Factor Levels**	**Low**	**High**
Planes	2	4	8
Ships	2	2	6
ECCs	2	2	6
ECC Vehicles	2	6	12
TSH Vehicles	2	6	12
SPOE Processing Stns	2	6	12
TSH Processing Stns	2	4	8
APOE Processing Stns	2	6	12
SH Processing Stns	2	4	12

[14] Sequential experimentation is the technique of "combining the runs of two (or more) fractional factorials to assemble sequentially a larger design to estimate the factor effects and interactions of interest" (Montgomery, 2009: 290).

4.4. Synthesis

The section detailed the results of employing the created simulation model to glean any implications about the real evacuation operation. Four scenarios were run in two OFAT experiments were run to demonstrate the application to deliberate or crisis action planning considerations and to diplomatic planning considerations. Two designed experiments were run to illustrate how this type of experiment produces more rigorous and descriptive results. Six measures of performance were defined for use as response variables in these experiments and, of course, could be exploited in future experiments. The results from first three scenarios highlighted the effectiveness in decreasing the maximum last evacuee time for the ECC by increasing the DoS ECC schedule to a 16-hour day, decreasing the maximum last evacuee time for the TSH and the maximum queue lengths by doubling all the transportation processing stations. Scenario four identified a bottleneck at the HN's port (i.e., SPOE) and found that increasing the number of port spaces past three didn't significantly decrease the evacuation completion time. The first designed experiment showed the complex interaction structure for the major elements of the ECC queueing system and how careful attention must be paid to which factor settings combinations affect the chosen MOP. Last, an addition run is done via a designed experiment to see if more efficiency can be gained at the port by increasing other major resources; the only deduction that could be made is increasing the number of airplanes significantly decreases the evacuation completion time. Understanding of the NEO system can be increased by running the prepared screening experiment at the end of Chapter 4.

Chapter 5: Discussion

5.1. Phase IV: 11. Documentation and Reporting

For the documentation of this simulation study, the graduate research project paper is the main source of information. This paper not only includes the final model and its statistical results for a choice few experiments; yet, it also captures intermediary planning documents and contemplation over why and how certain aspects of the model were developed. Additionally, this research project also includes a disc with all files concerning the final paper and model to support any quest to delve deeper into this topic.

5.2. Achieved Sponsor Directed Objectives

The following presents how the parts of this research project met specific objectives to serve the sponsor's needs. First developing the NEO conceptualization (see Figure A1) captures the general flow of evacuees by having all the evacuees flow through all the processes on the critical path; it models the lessons learned by the citizens by developing and incorporating the complacent delay arrival rate distribution; it finds the bottlenecks both by watching the model in animation mode and by the maximum queue length values; it integrates additional DoS personnel by being able to 'add' more ECCs and other servers at all the different DoS-owned processes; and it allows the EUCOM planners to address the pet issue by including an evacuee attribute that keeps track of which evacuees have pets. The model lets the planners go "above Algebra" by incorporating the complexity of the NEO system. This is demonstrated by the clearing processes the model imitates (i.e., one can visually see one part of the system clear out and then the next, and so on) when it is run in animation mode. A specific example is the experiment run on changing the number of port spaces. If the model kept with the original linear planning constraints then every increase in port spaces would produce an increase in the productivity of the evacuation operation; yet, the model emulates the complexities and interactions of an actual operation by indicating a point where no more efficiency can be gained by adding more resources. This experiment and the comparison of maximum queue lengths also showed the model's ability to identify bottlenecks. First, the reason the change from one to two and two to three port spaces made a difference was because the port is a bottleneck in the simulation. Also, the queue lengths show where evacuees are accumulating. Finally, the model – when validated – will be able to investigate relationships such as the effect that policy or planning changes have on the evacuation throughput or the effect that resource utilization has on evacuee wait time. This ability is shown in the designed experiments where changes in resource capacities were investigated for the effect on evacuation completion time.

5.3. Desirable Model Enhancements

In keeping with the continuous process improvement mantra, the model's performance and usability could be enhanced by making the following changes. First, the model would be a more robust tool if it allowed changes in the basic flow. This is rooted in the assumption that the evacuation will always go from the ECC to SPOE to TSH to APOE to SH; if there was another required travel leg; then the model would need to be drastically altered. If the model was transformed into sub-modules then each specific NEO scenario could be a combination of the three major transportation legs (e.g., land, sea and air travel) which would provide significant flexibility to plan each situation. Second, as with any computer program, this simulation model could be made more user friendly. Pollak et al. (2004) detail how they made their Arena® model easier to use by adding GUIs to lessen the burden on the user to learn the inner workings of the program and influence a higher usage rate of the simulation model with the HLS training department. Another addition along the same lines would be to complement this script with a 'how-to' manual specifically directed at making the model set-up more transparent for operational planning units such as EPOC. Finally, the most important improvement is to make the model more valid. The current bank of NEO data doesn't afford this task; thus the data requirements to beget this result are detailed in the next section.

5.4. Recommended Additional Research

As was stated in the section above, the model was not able to be completely validated as a simplified model of the NEO system. This implies that the data produced by the model is not necessarily representative of evacuation times seen in an actual operation. In order to achieve validation and make the simulation model's outputs an approximation of actual results, additional input data is needed. Specifically, data could be collected from mock NEO exercises to develop the distributions for evacuee arrival times, overall ECC processing times, individual ECC station processing times, processing times to administer each transportation leg to an evacuee, evacuee loading times for each possible transportation medium, capacity limitations for representative transportation mediums and processing times at a TSH and APOE. Additionally, taking record of the percentage of evacuees with pets, of each classification priority, of injured evacuees needing medical care, of evacuees interviewed, and of evacuees detained will provide realistic proportions to assign to the calling population of evacuees. (These percentages can be assigned to the attributes as discusses in Chapter 3 and Appendix C.) This range of input data would provide a comparison for the model's measure of system performance and thus make the validation step feasible.

5.5. USAFE/A9 Collaboration

Through the course of this research it was discovered that a similar project was directed within USAFE to the A9A shop. This office's objective for the study is to produce a "decision tool to model noncombatant flow during a hostile NEO" (Electronic Message, 16 Feb 2010). Because the scope is so parallel, it would be a shame to miss out on any collaboration from these separate studies. The point of contact for the USAFE study is Major Kevin Kennedy at Kevin.kennedy@ramstein.af.mil. This study also provides the answer to the resource requirements that EUCOM/J3 currently doesn't have to develop this NEO tool (i.e., Arena® software, programmer, and operations analyst). Foremost, the computer simulation software used to build this model is by commercial purchase only; yet, since Maj Kennedy is using the same software to complete his study, USAFE has it. Further, EUCOM will need a programmer to make any changes to or scenarios for the baseline model in Arena and an operations analyst to interpret the data and to do the statistical analyses. Again, as an AFIT PhD graduate, Maj Kennedy has all the skills to meet these needs; thus is an excellent resource to EUCOM. He has also been fully engaged in all the GCC exercises and planning regarding this topic so he has gathered SME inputs and garnered the knowledge from this level of involvement.

5.6. Conclusions

In conclusion, this study has gathered knowledge about what inputs and processes are important to include in the NEO system in order to accurately represent evacuee flow. The created model can be used as is as a tool for EUCOM planners to better communicate basic requirements between the service components and the Department of State personnel and to enhance their insight into the NEO process and understanding of potential interactions with in the NEO queueing system. Once validated, this simulation model is flexible enough to capture the main characteristics of any NEO and can offer J3 planners guidance for CONPLAN and OPLAN development (i.e., deliberate planning) and for rapid response needs it can provide vectors for crisis action planning.

Appendix A: NEO System Graphical Description

Appendix A includes the conceptualization of the NEO system and the ECC system. The next ten figures detail each process shown in the JTF/MNF line of the first figure (A1) as a basic queueing system.

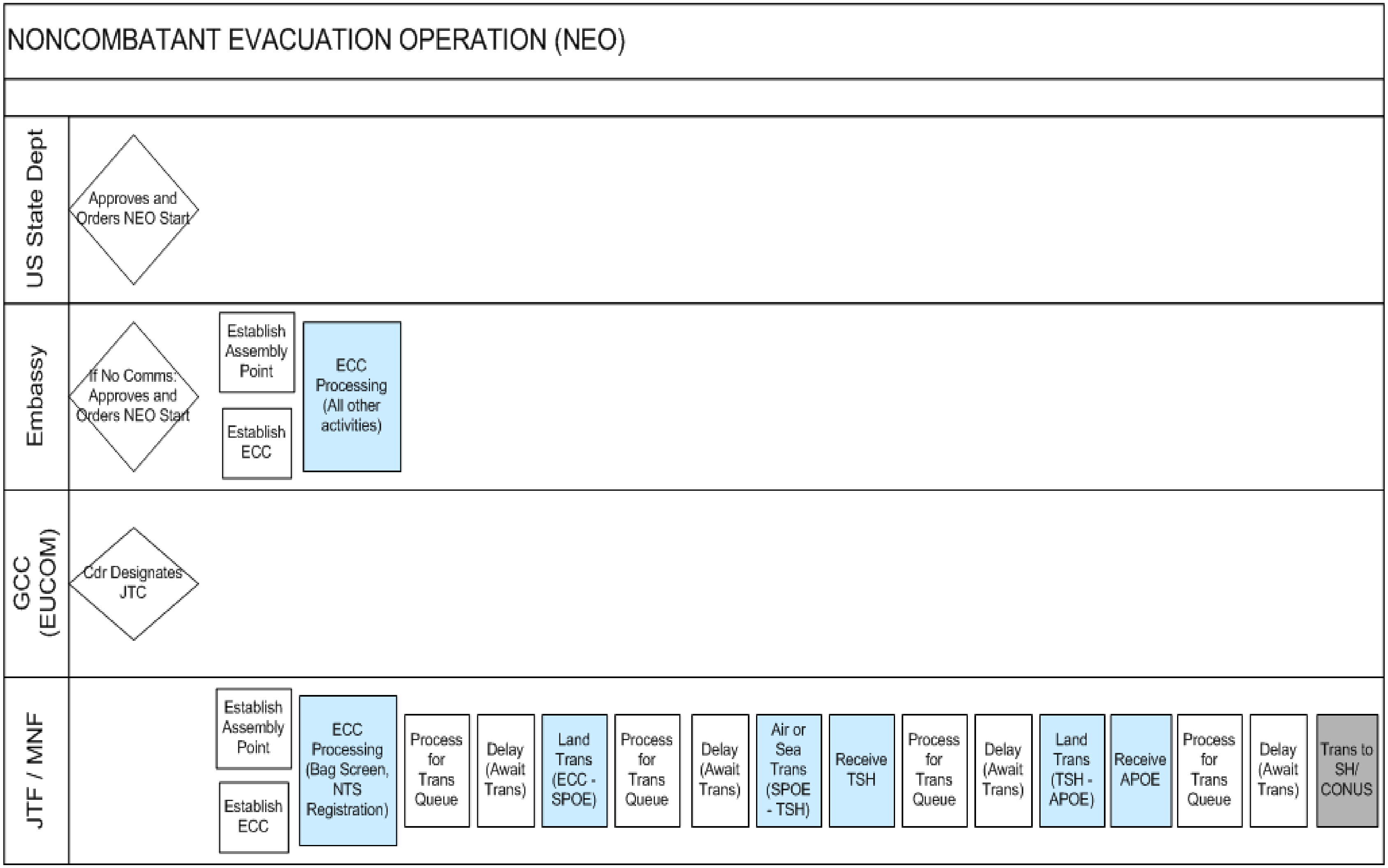

Figure A1. NEO Evacuee Flow

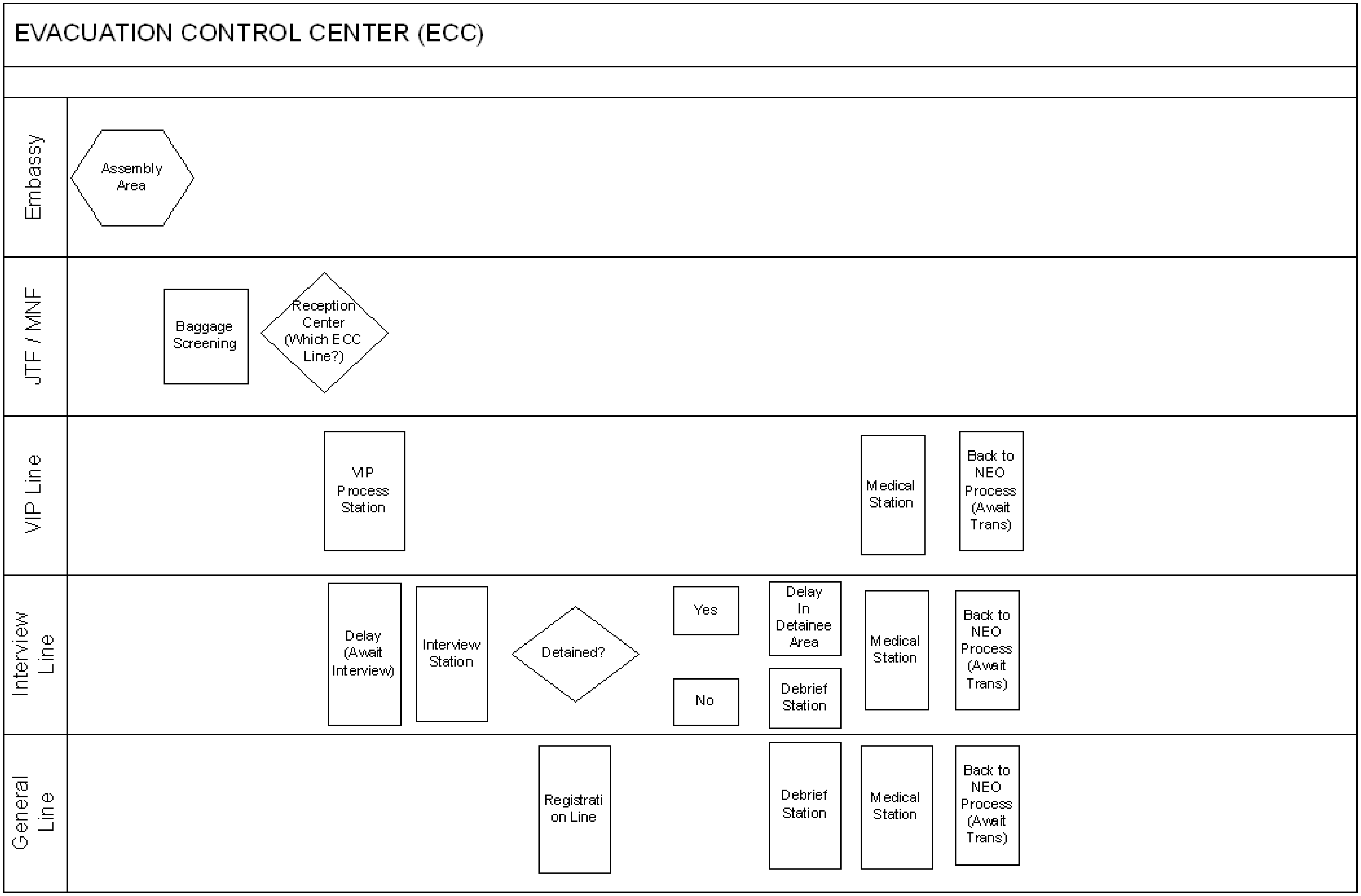

Figure A2. Potential ECC Set-Up and Evacuee Flow

Queueing System Representation for Each NEO System Process

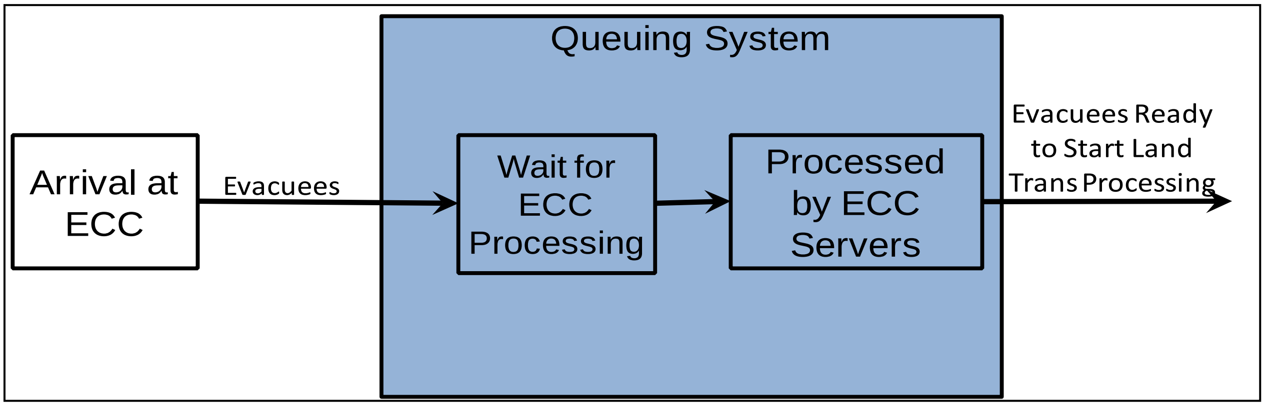

Figure A3. 1 - ECC Processing

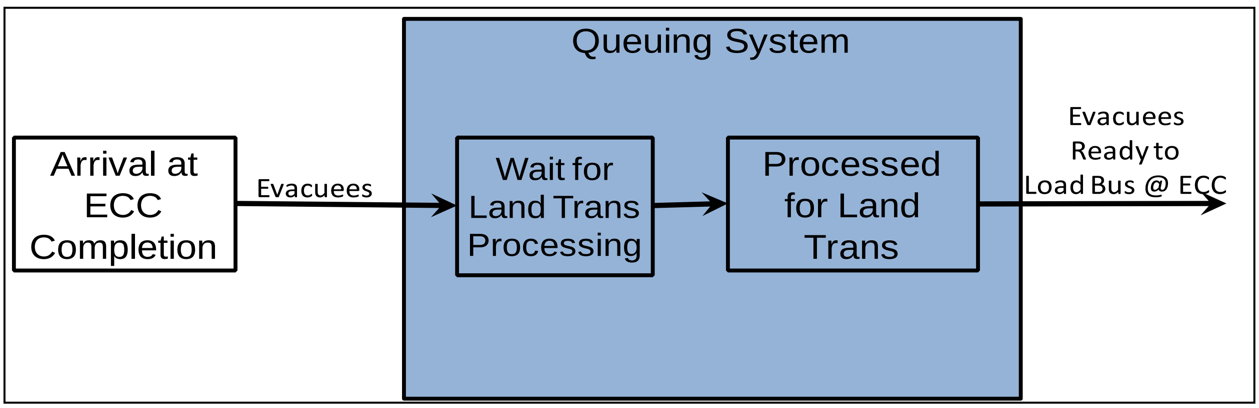

Figure A4. 2 & 3 - HN Land Transportation Processing

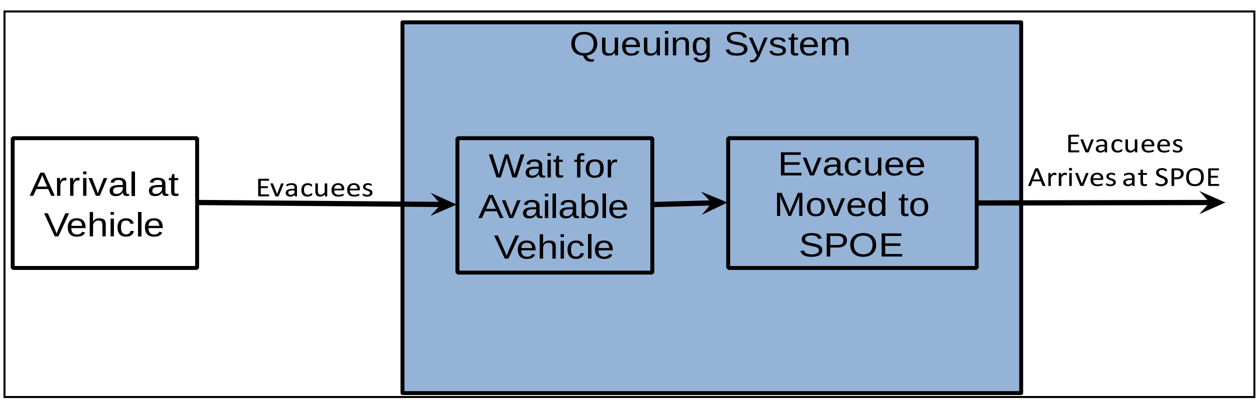

Figure A5. 4 – Land Transportation (ECC to SPOE)

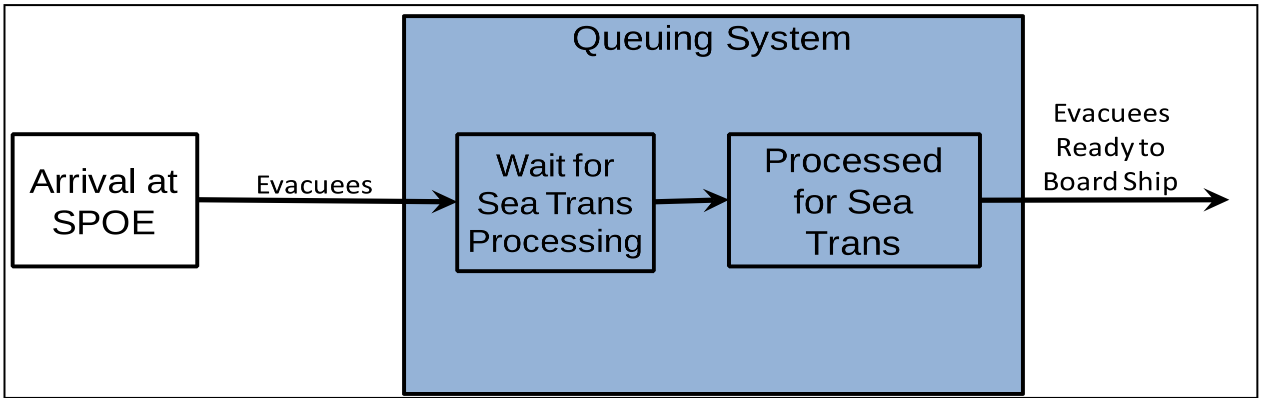

Figure A6. 5 & 6 – Sea Transportation Processing

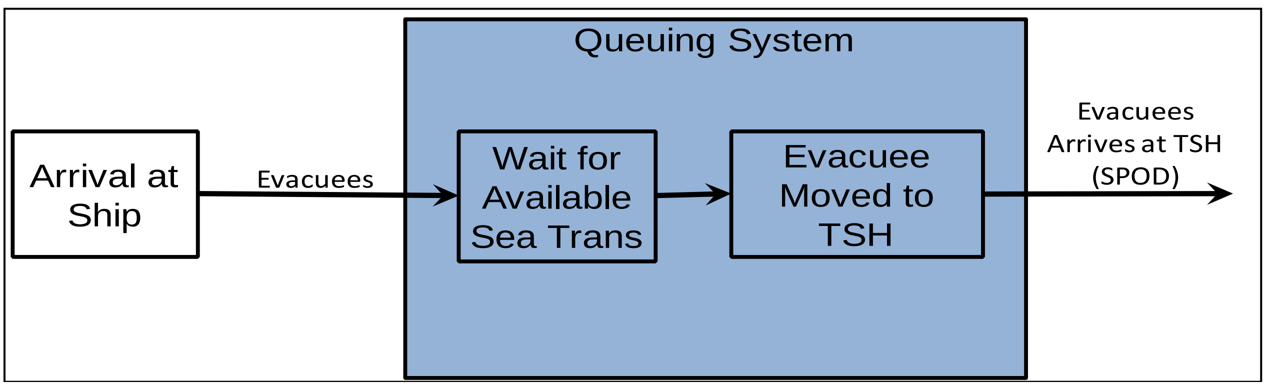

Figure A7. 7 – Sea Transportation (SPOE to TSH)

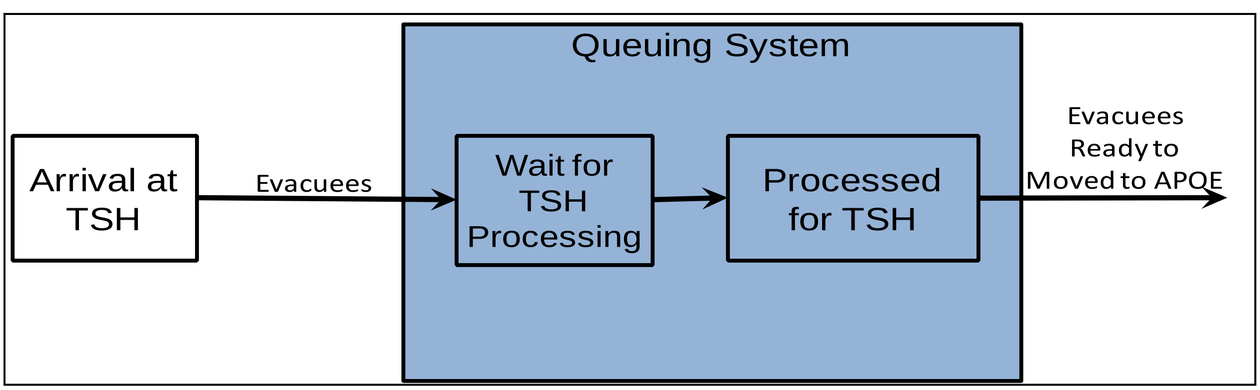

Figure A8. 8 – Receive TSH

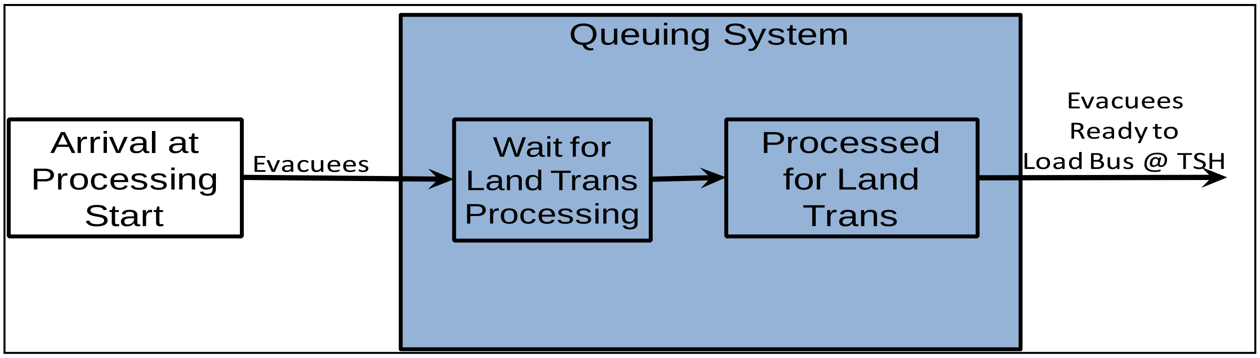

Figure A9. 9 & 10 – TSH Land Transportation Processing

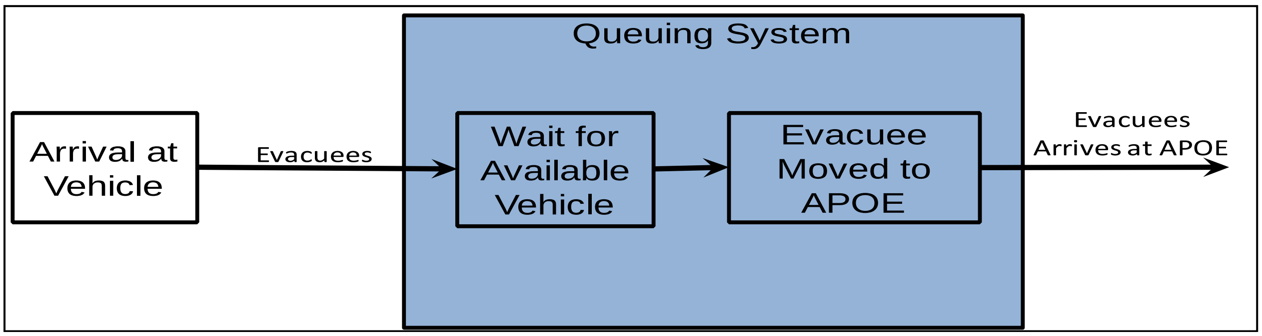

Figure A10. 11 - Land Transportation (TSH to APOE)

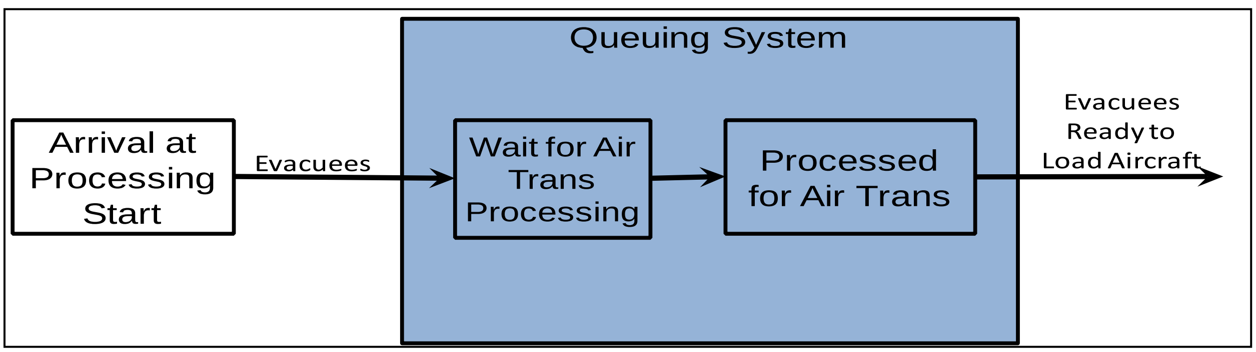

Figure A11. 12 - Receive APOE

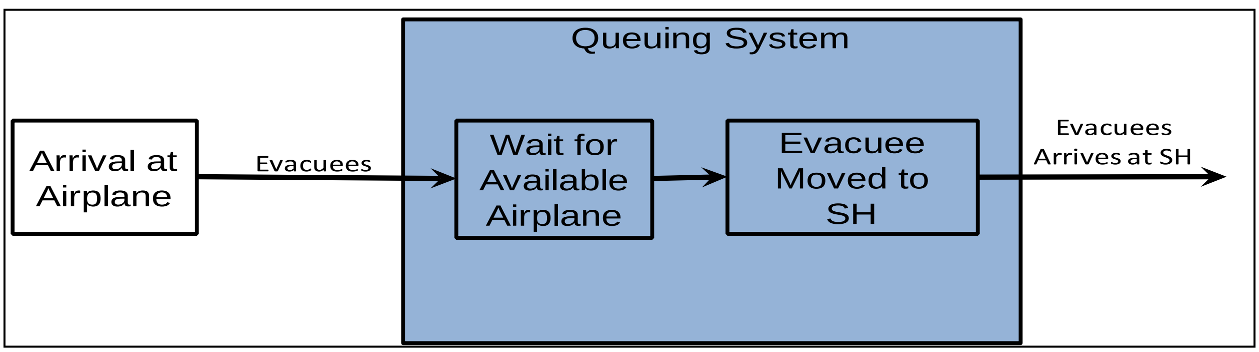

Figure A12. 13 – Air Transportation (APOE to SH)

Appendix B: Arena® Screen Shots

The following screen shots show how all the Arena® modules are arranged to model the NEO system. The figures were taken from the start of the model to its finish. The values and settings for each module are detailed in Appendix C.

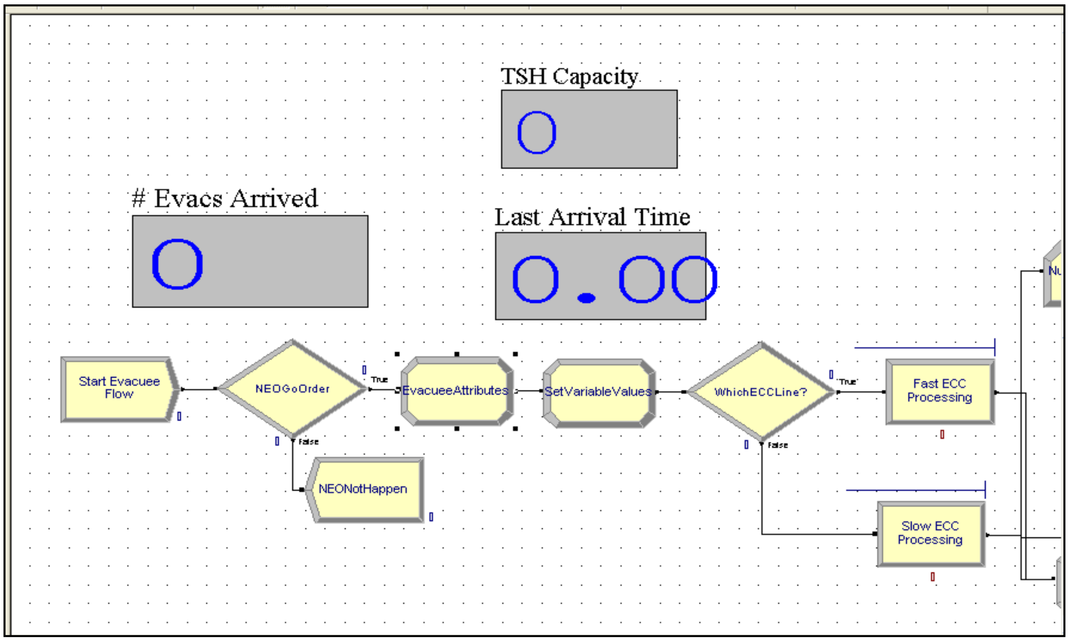

Figure B1. NEO Model Screen Shot #1

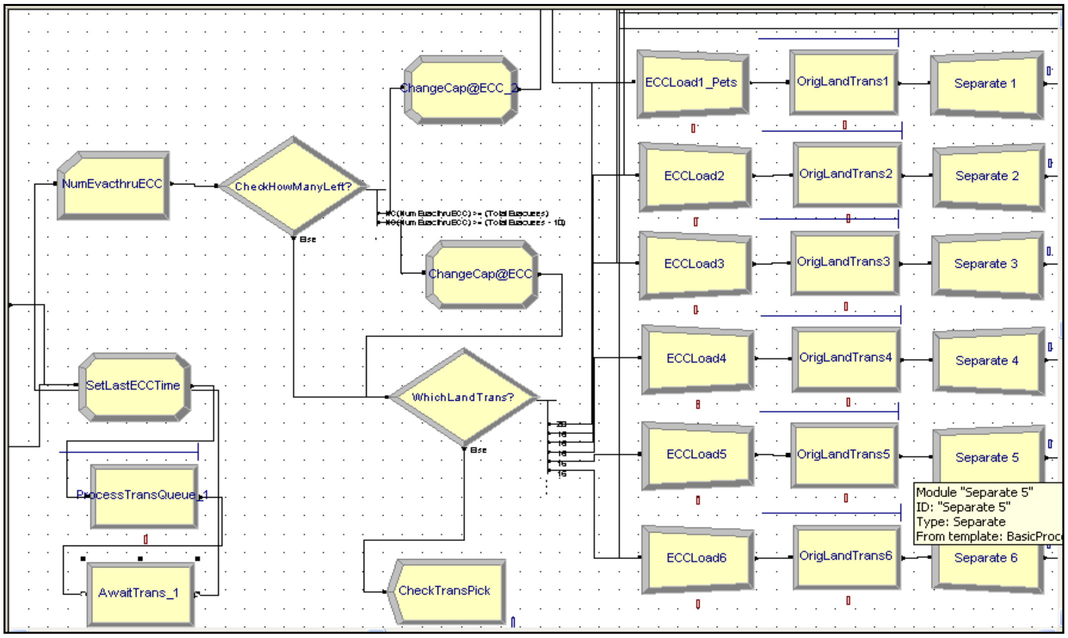

Figure B2. NEO Model Screen Shot #2

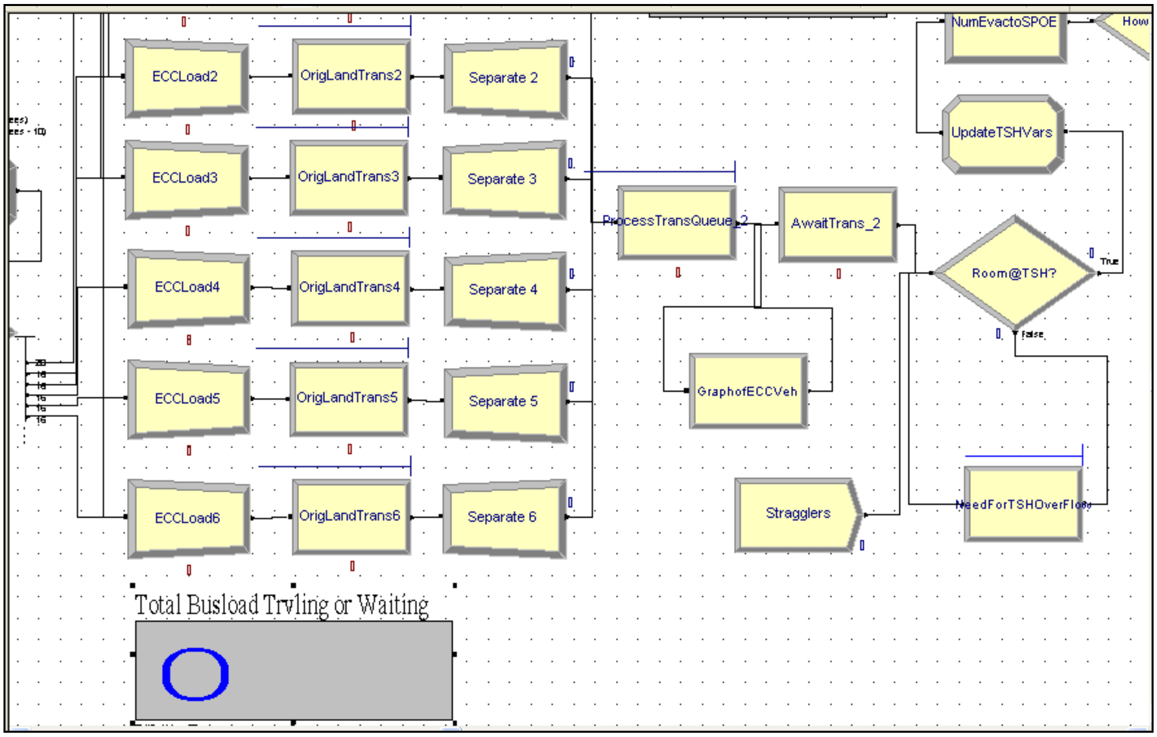

Figure B3. NEO Model Screen Shot #3 (For Counter Only)

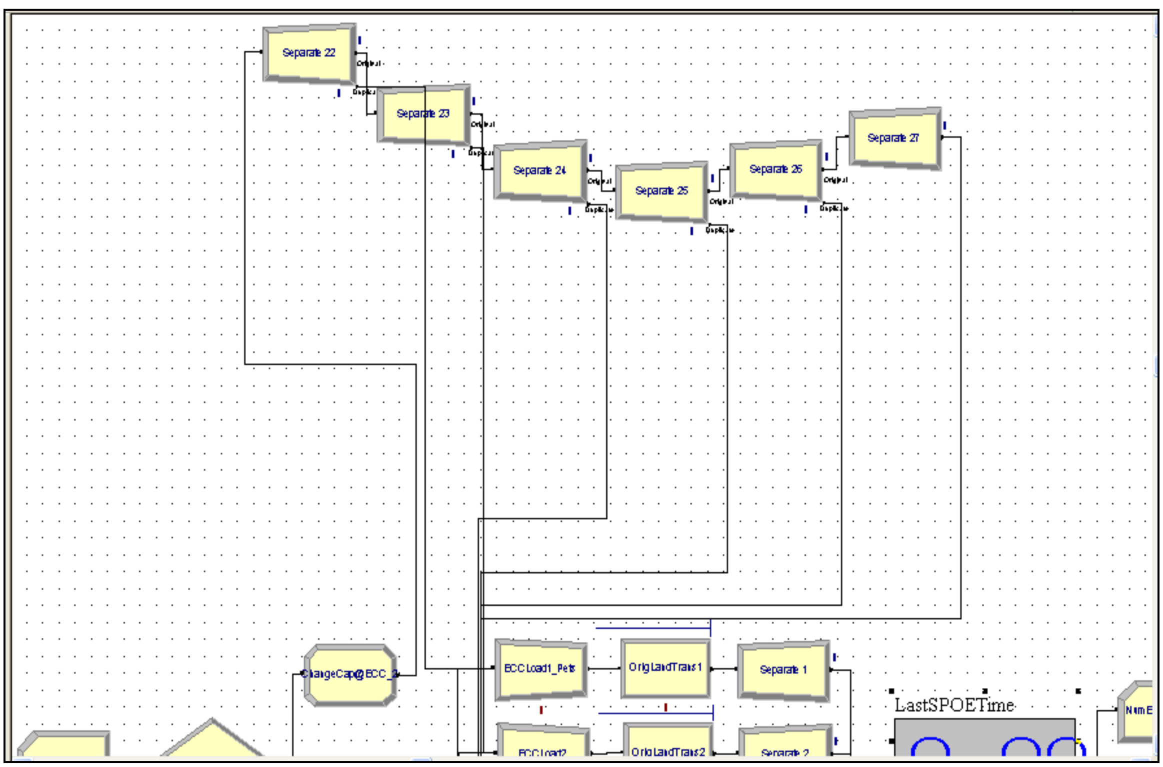

Figure B4. NEO Model Screen Shot #4

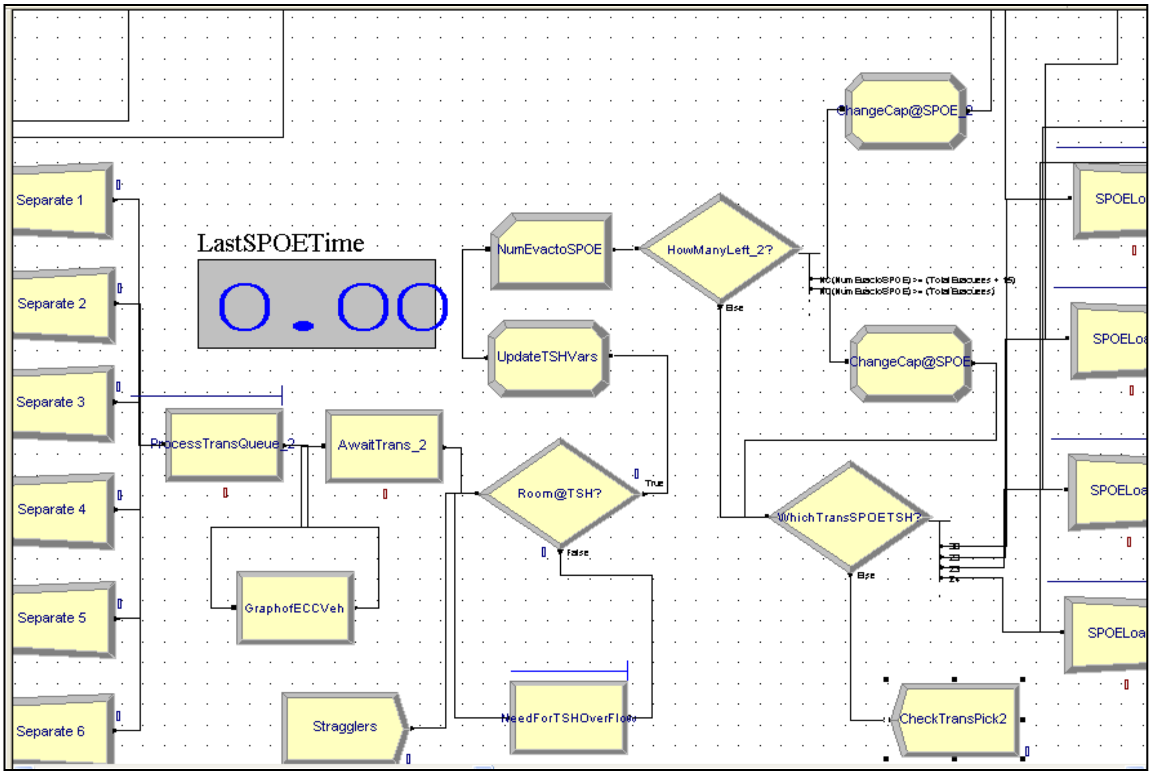

Figure B5. NEO Model Screen Shot #5

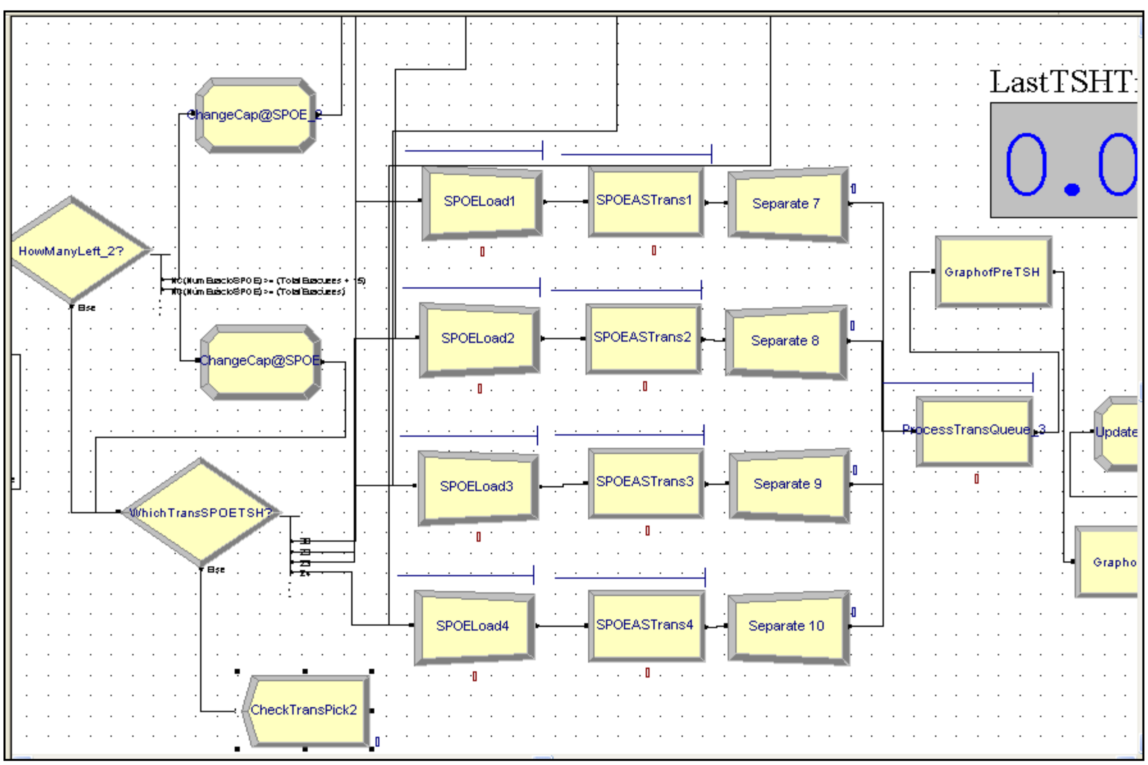

Figure B6. NEO Model Screen Shot #6

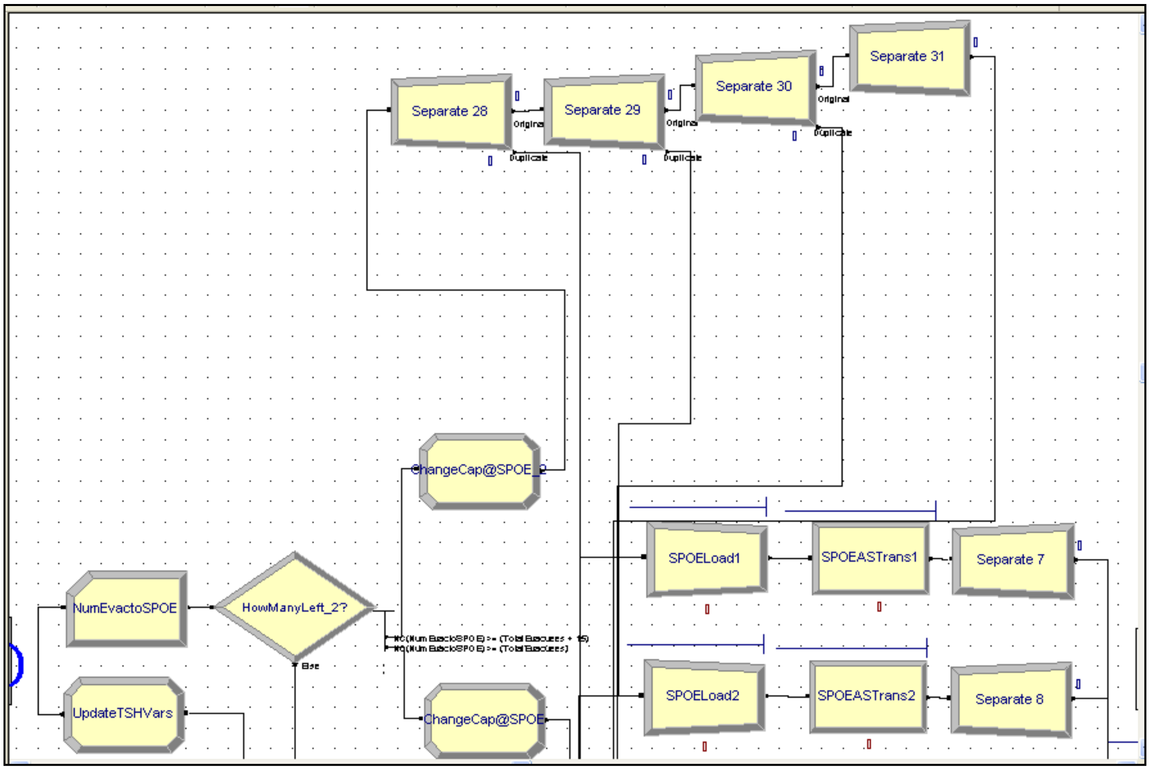

Figure B7. NEO Model Screen Shot #7

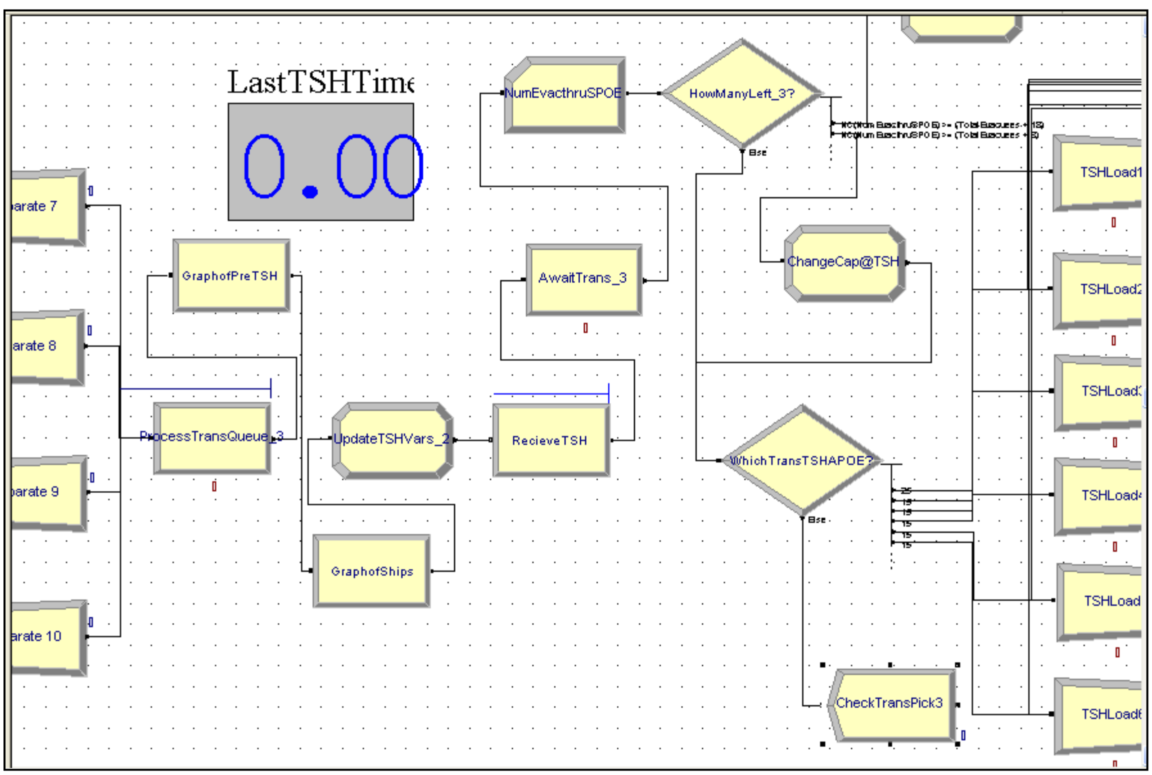

Figure B8. NEO Model Screen Shot #8

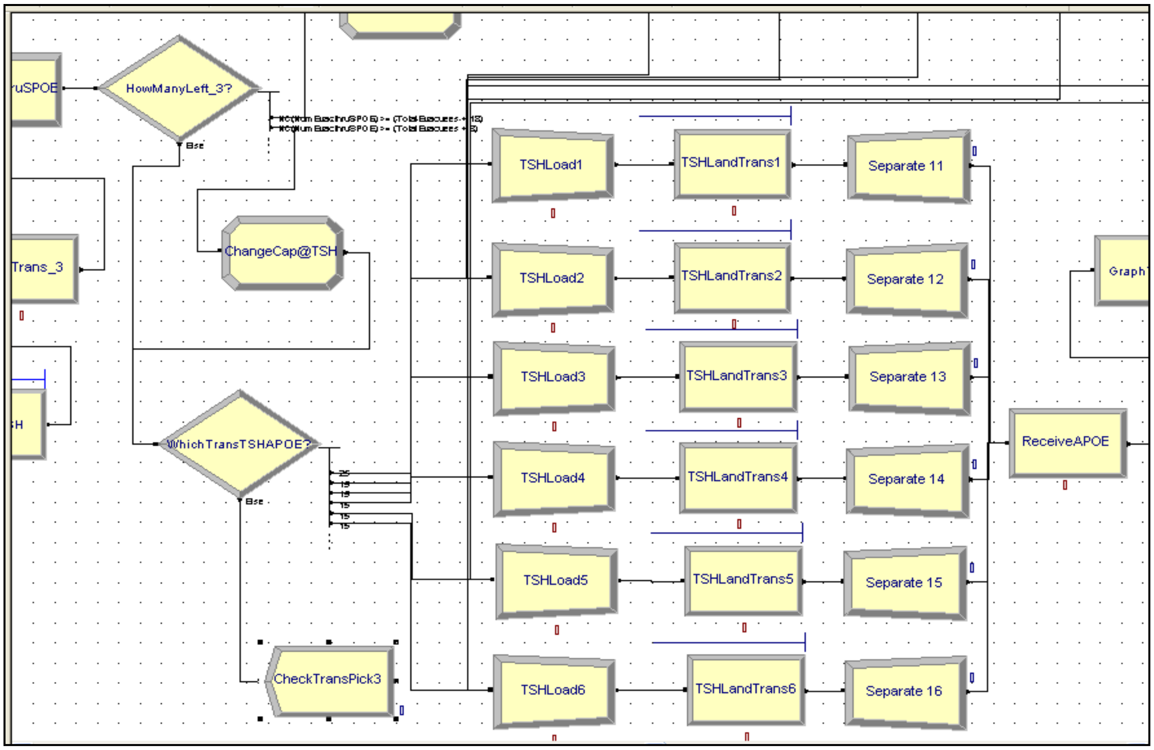

Figure B9. NEO Model Screen Shot #9

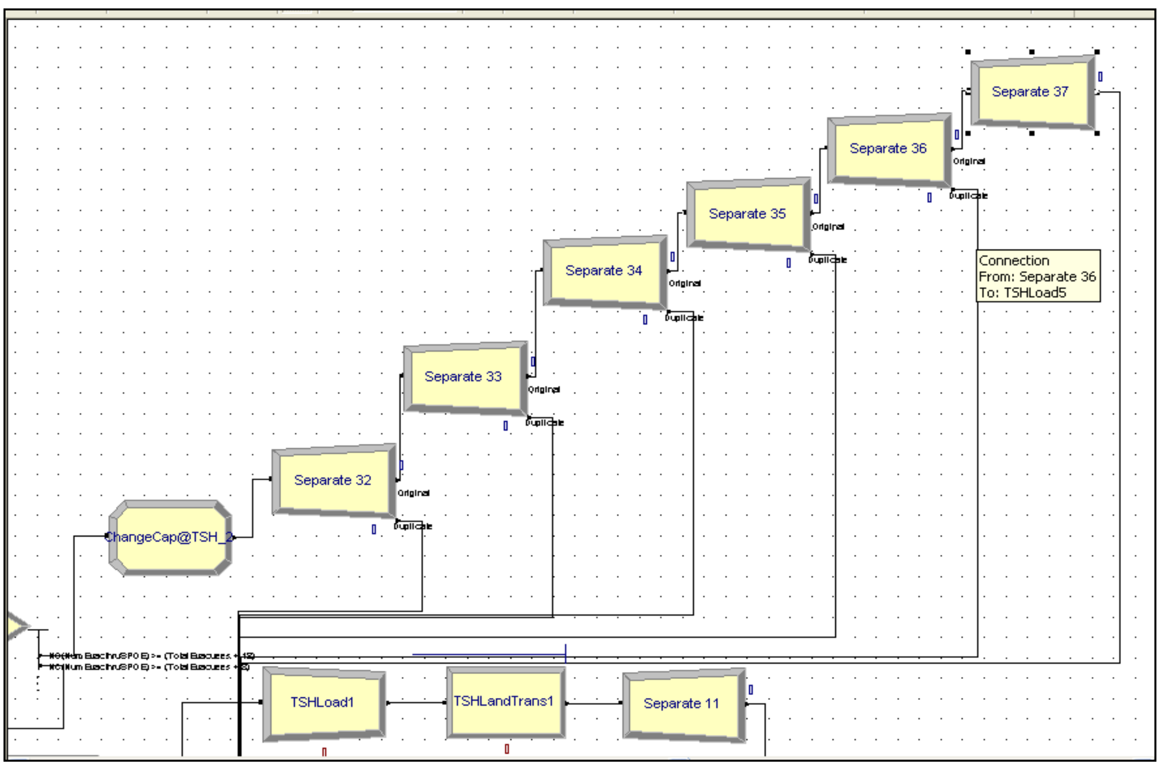

Figure B10. NEO Model Screen Shot #10

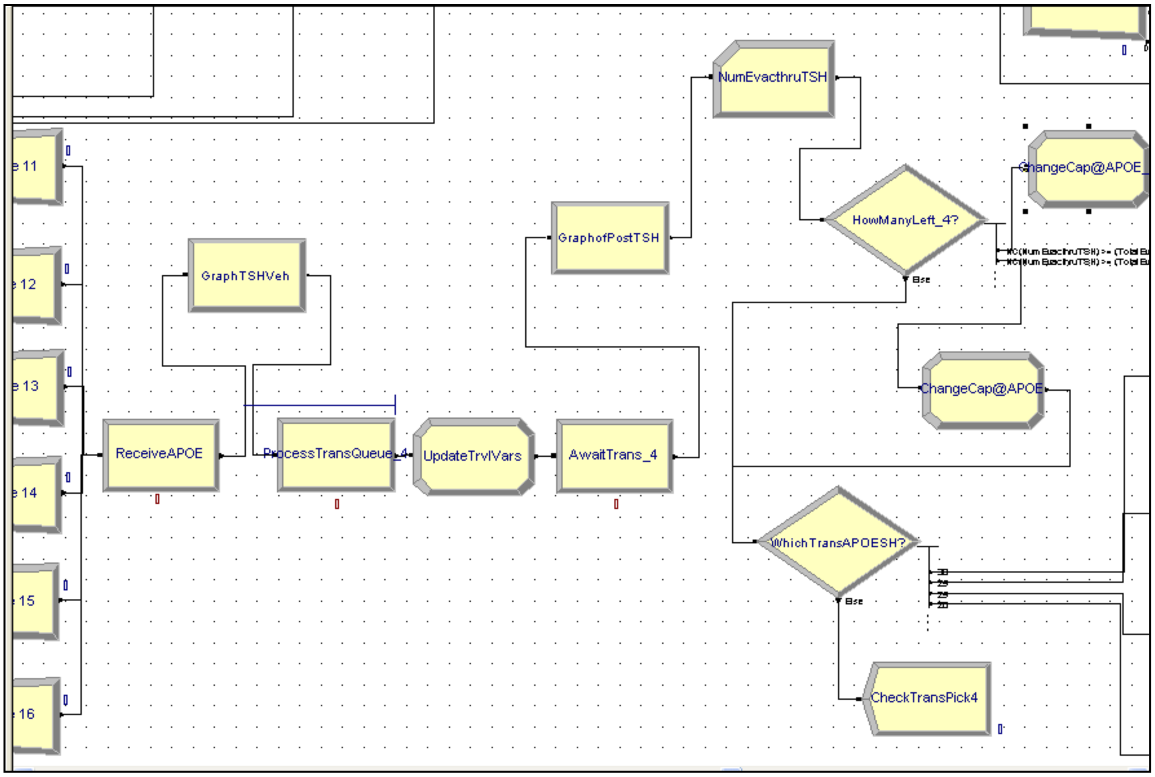

Figure B11. NEO Model Screen Shot #11

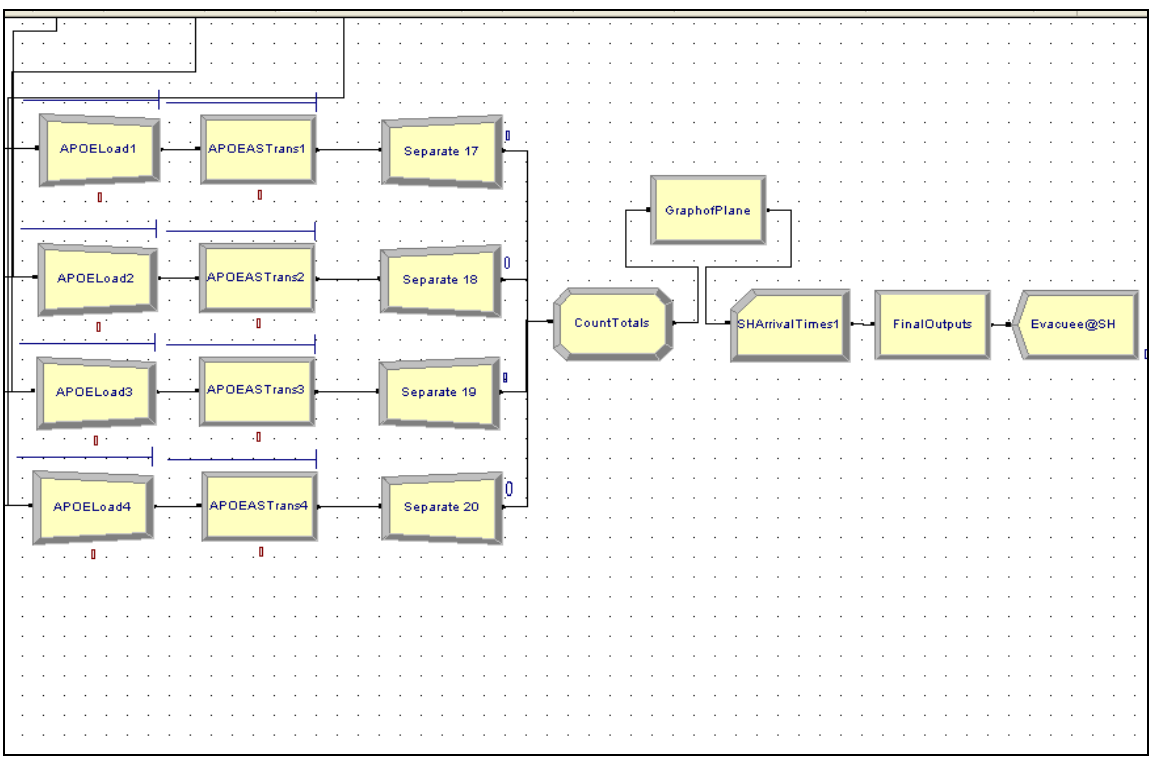

Figure B12. NEO Model Screen Shot #12

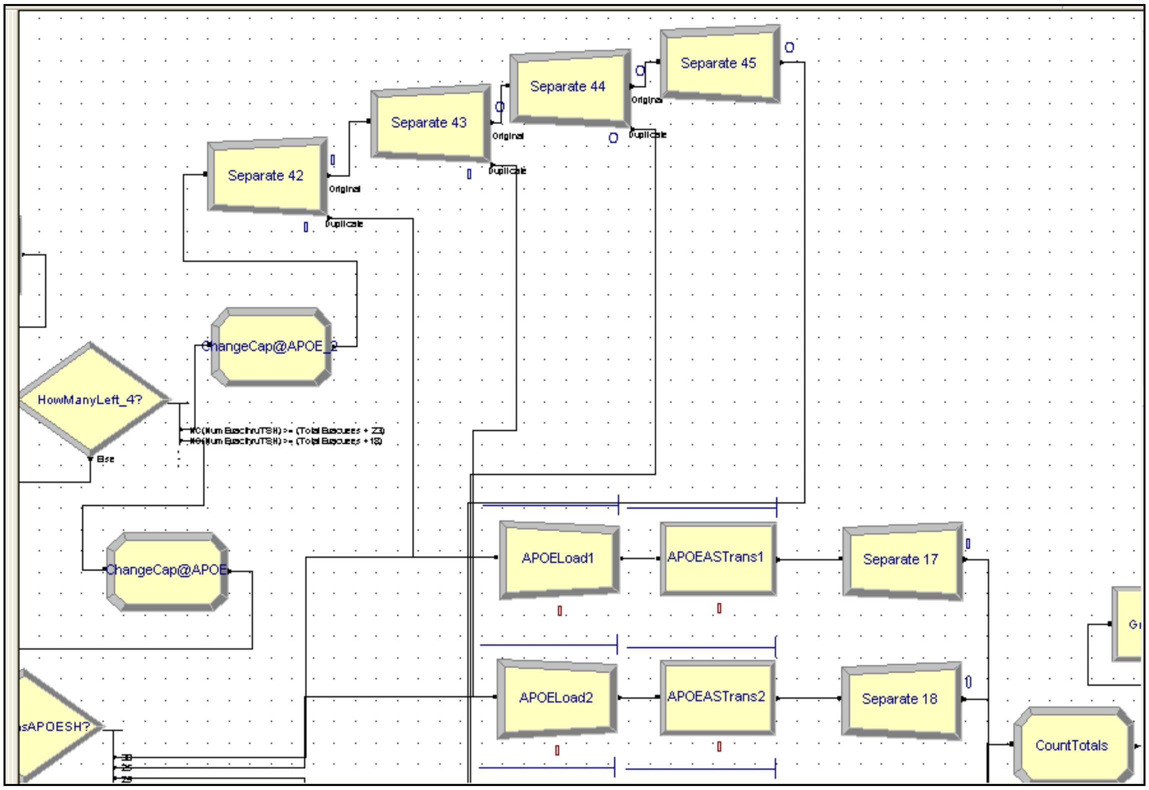

Figure B13. NEO Model Screen Shot #13

Appendix C: Arena® Modules for Model Translation

Appendix C explains how each module shown in the screen shots from Appendix B needs to be inputted – specifically which variable, what each variable value is, and any equations used to define variables especially created for this model. Additionally, the following itemization explains why each module was included and any special simulation technique employed.

Arena ® Module Descriptions

"Start Evacuee Flow" Create Module: Time Between Arrivals: Both the triangular and uniform distribution are used to describe entity arrivals. According to Banks et al. (2005: 160), these two distributions can be used in the case of limited data collection as is the situation for the NEO system. The distributions are listed in Table 9. Entities Per Arrival is logically the number of entities created at each arrival time. The model uses a variable, "EntitiesPerArrival", to hold the value for this field. Max Arrivals is the total number of arrivals the create module will execute. The model uses a variable, "MaxArr", to hold the value for this field. Thus, the number of total entities is just the entities per arrival multiplied by the maximum arrivals; the model multiplies these variables to set the variable, "TotalEvacuees". In order to keep the verification of the interarrival rates applicable; in order to increase the number of evacuees, only the "EntitiesPerArr" variable is changed; thus "MaxArr" is always set to 200.

First Creation: An entity's first possible arrival is the first time the ECC opens on the first day as determined by the ECC schedule. This is 0600 (6 hours) for the 12-hour schedule; 0400 (4 hours) for the 16-hour schedule; and 0200 (2 hours) for the 20-hour schedule. Since the interarrival distributions are defined in seconds; the above times translate to 21,600, 14,400, and 7,200 seconds respectively.

"NEOGoOrder" Decide Module: This decide module represents whether the ambassador or COM has ordered the evacuation. It uses the variable, "AmbOrderNEO," whose initial value is one, to allow the evacuees to continue onto the NEO system or to be disposed. If "AmbOrderNEO" is equal to one then the module's condition is true and thus evacuees continue. If this variable was set to zero, all the entities are immediately discarded to the "NEONotHappen" Dispose module. This logic represents a possibility for the model to include and time events in-between this order and the establishment of the ECC. The last case of being immediately disposed is meant to be a place holder for potential contingencies of evacuees arriving early to the assembly point.

"EvacueeAttributes" Assign Module: The attributes shown in Table 10 below are assigned to each entity after they are created. These can be used to prioritize entities in the various system queues. These attributes were not explicitly used since there is historical data based estimate to translate into the portion of which the calling population these will consist. Yet, if one wanted to explore the effect 25 percent of the evacuees having pets had the system then a value of 0.00 to 0.25 for the attribute HavePets would be manipulated differently as representative of an evacuee who had a pet.

Table C1. Evacuee Attributes in Arena®

Baseline Model		
Attribute Name	Distribution	Stream
LoadTime	UNIF(0,1)	1
HavePets	UNIF(0,1)	2
AreClass	UNIF(0,1)	3
AreInjured	UNIF(0,1)	4
AreInterview	UNIF(0,1)	5
AreDetained	UNIF(0,1)	5

“SetVariableValues” Assign Module: This assign module sets the scenario-specific values for the following variables if these variables’ initial value is set to zero. The definition for what the variable is to represent and any associated equation or function is also provided.

1. TotalEvacuees is the value of MaxArr * EntitiesPerArr
2. TSHCapacity – is set to 10 percent of the total evacuees
3. LastArrivalTime is set to Entity.StartTime and represents the current value of the last entity to enter the system.
4. TransCap_ECCSPOE_*N* (*N* = 1, 2,…,6), TransCap_SPOETSH_*N* (*N* = 1, 2,…4), TransCap_TSHAPOE_*N* (*N* = 1, 2,…,6), TransCap_APOESH_*N* (*N* = 1, 2,…, 4) are all set to the general capacity for their respective batching modules. For example, this means that every vehicle transporting evacuees from the ECC to the SPOE has the same capacity. Having a different capacity for each batching module allows for more flexibility in each transportation medium capacity if one wanted to have different capacities for each specific transport.

“WhichECCLine” Decide Module: This is a 2-way by condition decision and sends entities to the “Fast ECC Processing” module if the number in the fast ECC process queue is less than the number in the slow ECC process queue or

NQ(Fast ECC Processing.Queue) < NQ(Slow ECC Processing.Queue);

else the entity goes to the “Slow ECC Processing” module.

“Fast ECC Processing” Process Module: This module uses the logic action of Seize Delay Release with High(1) priority; it uses one Fast ECC Server and follows the distribution UNIF(0.5, 0.6) in minutes with random number generator stream seven. This is a standard type and uses value added allocation.

"Slow ECC Processing" Process Module: This module uses the logic action of Seize Delay Release with High(1) priority; it uses one Slow ECC Server and follows the distribution UNIF(0.6, 0.75) in minutes with random number generator stream eight. This is a standard type and uses value added allocation.

"SetLastECCTime" Assign Module: This assign module sets ECC-related variables if these variables' initial value is set to zero. The definition for what the variable is to represent and any associated equation or function is also provided.

TotOrigLandTrans represents the total number of land vehicles currently being used (i.e. work in progress (WIP)) in the process modules OrigLandTrans; it is set to the

$$Eqn\ (3.1): TotOrigLandTrans = \sum_{N=1}^{6} OrigLandTransN.WIP\,.$$

LastECCTime is set to TNOW[15]and represents the current time value of the last entity to complete the ECC process.

"ProcessTransQueue_1" Process Module: This module uses the logic action of Seize Delay Release with Medium(2) priority; it uses one TransQStnsECCSPOE and has a constant delay set to "DetProcessTime" variable value in minutes. This is a standard type and uses value added allocation.

"AwaitTrans_1" Process Module: This module uses the logic action of Delay and has a constant delay set to "DetWaitingTime" variable value in minutes. This is a standard type and uses value added allocation.

[15] TNOW is the abbreviation in Arena for the simulation clock time.

"NumEvactoECC" Record Module: This is a Count type with value equal to one. This counter represents all the entities that have made it past the ECC in the NEO system.

"CheckHowManyLeft?" Decide Module: This module is an N-way by condition decide where N = 3. If NC(NumEvacthruECC) >= (TotalEvacuees - 10) , then the entities go to the "WhichLandTrans?" Decide module. If NC(NumEvacthruECC) >= TotalEvacuees, then the entities go to "ChangeCap@ECC" module. Else entities go to "ChangeCap@ECC_2" module. This mechanism is used for all four traveling queue representations and is using the count of how many entities have gone through that point in the system and compares that count with the total number of entities. Once all but ten entities have gone through the land transportations' capacities are lowered to recognize the system's need to compensate for only a few entities left in the system. At the last entity, the second assign module changes all the capacities to one such that all entities move on and the separate modules are used to ensure all batching modules are emptied.

"WhichLandTrans?" Decide Module: This is an N-way by chance decide where N = 6. The chance of selecting the six land transportation vehicles are set to 20, 16, 16, 16, 16, 16 – each which lead into the six batch modules for SPOE transportation.

"CheckTransPick" Dispose Module: This dispose module is a verification check; if any entities go to this module, then the decide module is not working properly.

"ChangeCap@ECC" Assign Module: This assigns a new value of eight for each of the variables TransCap_ECCSPOE_N for N = 1, 2,…, 6. The model effectively lowers all land transportation medium's capacity to eight to represent the real-world evacuation phenomenon where the number of evacuees needing to be transported significantly decreases toward the end of the evacuation.

"ChangeCap@ECC_2" Assign Module: This assigns a new value of NQ(ECCLoad1_Pets.Queue) + 1 for the variable TransCap_ECCSPOE_1. Additionally it assigns a new value of NQ(ECCLoadN.Queue) + 1 for the variable TransCap_ECCSPOE_*N* for $N = 2, 3, \ldots, 6$. This sets the capacity to the current queue length (or number waiting to be batched) plus one for the current entity.

"ECCLoad1_Pets" Batch Module: This is a temporary type with batch size of TransCap_ECCSPOE_1. It also uses the save criterion as last and any entity rule.

"ECCLoad*N*" Batch Module (for *N* = 2, 3,…, 6): This is Temporary type with batch size of TransCap_ECCSPOE_*N* (for $N = 2. 3, \ldots, 6$). It also uses the save criterion as last and any entity rule.

"OrigLandTrans*N*" Process Module (for *N* = 1, 2,…, 6): This module uses the logic action of Seize Delay Release with Medium(2) priority; it uses one LandTrans and has a constant delay set to the expression

$$Eqn\ (3.2): Delay = 1/(AvgLandTransSpeedmph / \mathrm{ECCSPOEDistance})$$

in hours. This is a standard type and uses value added allocation.

"Separate *N*" Separate Module (for *N* = 1, 2,…, 6): This module is a split existing batch, and member attributes retain original entity values. This simulates the passengers on a bus or other land transport exiting the medium.

"Separate *N*" Separate Module (for *N* = 22, 23,…, 27): When the last entity goes through "CheckHowManyLeft?" all the batches waiting to be filled to a certain capacity must be easily emptied – otherwise the simulation won't complete. The separate module is a duplicate original type with zero percent cost to duplicates and one (1) duplicate. Thus the last entity is duplicated in the separate modules N-1 times and the original entity and each duplicate clears out the N batch modules. The last separate module splits the existing batch and retains original entity attribute values ($N = 6$).

"ProcessTransQueue_2" Process Module: This module uses the logic action of Seize Delay Release with Medium(2) priority; it uses one TransQStnsSPOETSH and has a constant delay set to "DetProcessTime" variable value in minutes. This is a standard type and uses value added allocation.

"AwaitTrans_2" Process Module: This module uses the logic action of Delay has a constant delay set to "DetWaitingTime" variable value in minutes. This is a standard type and uses value added allocation.

"Room@TSH" Decide Module: As explained earlier, this is a 2-way by condition that checks to see if there is enough room for the next entity at the TSH. If

$$Eqn\ (3.3): TotalNum@TSH < (TSHCapacity - (0.05 * TSHCapacity))$$

is true, then the entity continue in the system and on to the next process. If it is false, the entity goes to the "NeedForTSHOverFlow" hold module.

"NeedForTSHOverFlow" Hold Module: This hold module scans for a condition which equals the inequality in "Room@TSH" decide module. As long as the condition is false, the entities remain. As soon as the variable, "TotalNum@TSH" is updated and meets the criteria; all entities in this hold are released. Because Arena® adheres to the FCFS queue discipline, if there are also entities finishing at "AwaitTrans_2" when the hold condition becomes true, the entities in the hold go before entities come out of “AwaitTrans_2.” This represents the amount of overage the planners can expect at the TSH given the assigned limit to its capacity.

“Stragglers” Create Module: This module is how to represent evacuees who appear at points in the process without accomplishing all the required processes before the current process. The event where an evacuee arrives at the SPOE without having processed through the ECC is a common occurrence in a NEO (Moulton, 2010). Entity type is evacuee, time between arrival is constant at 0.3 hours and entities per arrival, max arrivals, and first creation is one, ten, and 30 hours respectively.

“UpdateTSHVars” Assign Module: This assigns values for TotalNum@TSH, LastSPOETime, TotSPOEASTrans, and updates TotOrigLandTrans using *Eqn* (3.1). The total number at the TSH is found by summing all entities in the TSH as shown in *Eqn* (3.4) below. LastSPOETime is set to TNOW and represents the current time value of the last entity to complete the SPOE process. TotSPOEASTrans is the number of sea transports that are currently being used (i.e., WIP) in the process modules SPOEASTrans*N* and is given in *Eqn* (3.5) below.

$$Eqn\ (3.4): TotalNum@TSH =$$

$$\text{ProcessTransQueue\_3.WIP} + \text{AwaitTrans\_3.WIP} + \text{NQ(RecieveTSH.Queue)} + \sum_{N=1}^{6} NQ(TSHLoadN.Queue + \; + \sum_{N=1}^{6} TransCapTSHAPOE\_N * TSHLandTransN.WIP$$

$$Eqn\ (3.5): TotSPOEASTrans = \sum_{N=1}^{4} SPOEASTransN.WIP$$

"NumEvactoSPOE" Record Module: This is a Count type with value equal to one. This counter represents all the entities that have made it to the SPOE in the NEO system.

"HowManyLeft_2?" Decide Module: This module is an N-way by condition decide where N = 3. If NC(NumEvactoSPOE) >= (TotalEvacuees) , then the entities go to the "WhichTransSPOETSH?" Decide module. If NC(NumEvactoSPOE) >= (TotalEvacuees + 15), then the entities go to "ChangeCap@SPOE" module. Else entities go to "ChangeCap@SPOE_2" module. Once all entities have gone through the sea transportations' capacities are lowered to recognize the system's need to compensate for only a few entities left in the system. At the last entity, the second assign module changes all the capacities to one such that all entities move on and the separate modules are used to ensure all batching modules are emptied.

"WhichTransSPOETSH?" Decide Module: This is an N-way by chance decide where N = 4. The chance values are set to 30, 23, 23, 24 which lead into the four batch modules for transportation to the TSH.

"CheckTransPick2" Dispose Module: This dispose module is a verification check; if any entities go to this module, then the decide module is not working properly.

"ChangeCap@SPOE" Assign Module: This module shows a different type of logic that can be used to reassign the transportation capacities. First, the variable "MaxofSPOEs" finds the maximum values of all the batches' queue lengths thus

MaxofSPOEs = Max of {NQ(SPOELoad*N*.Queue} for *N* = 1, 2,…, 4.

Then assigns this value for each of the variables TransCap_SPOETSH_*N* for *N* = 1, 2,…, 4. The model effectively lowers the sea-faring transportation mediums' capacity to the maximum queue length of all four.

"ChangeCap@SPOE_2" Assign Module: This assigns a new value of NQ(SPOELoad*N*.Queue) + 1 for the variable TransCap_SPOETSH_*N*. *N* = 1, 2,…, 4. This sets the capacity to the current queue length (or number waiting to be batched) plus one for the current entity.

"SPOEEvac*N*" Batch Module (for *N* = 1, 2, …, 4): This is temporary type with batch size of TransCap_SPOETSH_*N* (for *N* = 1, 2, …, 4). It also uses the save criterion as last and any entity rule.

"SPOEASTrans*N*" Process Module (for *N* = 1, 2, …, 4): This module uses the logic action of Seize Delay Release with Medium(2) priority; it uses one AirSeaTransToTSH and uses the uniform distribution, UNIF(60,240) minutes, for the delay time. Also the expression uses random number stream nine (9).

"Separate *N*" Separate Module (for *N* = 7, 8, …, 10): This module is a split existing batch and member attributes retain original entity values. This simulates the passengers on a ship or other sea transport exiting the medium.

"Separate *N*" Separate Module (for *N* = 28, 29,…, 31): When the last entity goes through "HowManyLeft_2?" all the batches waiting to be filled to a certain capacity must be easily emptied – otherwise the simulation will not complete. The separate module is a duplicate original type with zero percent cost to duplicates and one (1) duplicate. Thus the last entity is duplicated in the separate modules *N*-1 times and the original entity and each duplicate clears out the *N* batch modules. The last separate module is a split existing batch, and member attributes retain original entity values. (*N* = 4)

"ProcessTransQueue_3" Process Module: This module uses the logic action of Seize Delay Release with Medium(2) priority; it uses one TransQStnsTSHAPOE and has a constant delay set to "DetProcessTime" variable value in minutes. This is a standard type and uses value added allocation.

"UpdateTSHVars_2" Assign Module: This module updates TotalNum@TSH and TotSPOEASTrans variable whose equations are given above. LastTSHTime is set to TNOW and represents the current time value of the last entity to complete the TSH process. TotTSHLandTrans is the number of land transportation mediums which are currently being used (i.e., WIP) in the process modules TSHLandTrans*N*.

$$Eqn\ (3.6): TotTSHLandTrans = \sum_{N=1}^{6} TSHLandTransN.WIP$$

"RecieveTSH" Hold Module: This module represents the holding area on the TSH. Entities wait here while Eqn (3.7) holds true.

$$Eqn\ (3.7): \sum_{N=1}^{4} APOEASTransN.WIP \leq 4$$

"AwaitTrans_3" Process Module: This module uses the logic action of Delay has a constant delay set to "DetWaitingTime" variable value in minutes. This is a standard type and uses value added allocation.

"NumEvacthruSPOE" Record Module: This is a Count type with value equal to one. This counter represents all the entities that have made it past the SPOE in the NEO system.

“HowManyLeft_3?” Decide Module: This module is an N-way by condition decide where N = 3. If NC(NumEvacthruSPOE) >= (TotalEvacuees + 8) , then the entities go to the “WhichTransTSHAPOE?” Decide module. If NC(NumEvacthruSPOE) >= (TotalEvacuees + 18), then the entities go to “ChangeCap@TSH” module. Else entities go to “ChangeCap@TSH_2” module. Once all entities have gone through the land transportations’ capacities are lowered to recognize the system’s need to compensate for only a few entities left in the system. At the last entity, the second assign module changes all the capacities to one such that all entities move on and the separate modules are used to ensure all batching modules are emptied.

“WhichTransTSHAPOE?” Decide Module: This is an N-way by chance decide where N = 6. The chance values are set to 25, 15, 15, 15, 15, and 15 which lead into the six batch modules for transportation to the APOE.

“CheckTransPick3” Dispose Module: This dispose module is a verification check as if any entities go to this module, then the decide by chance is not working properly.

“ChangeCap@TSH” Assign Module: This assigns a new value of twenty (20) for each of the variables TransCap_TSHAPOE_*N* for *N* = 1, 2, …, 6. The model effectively lowers all the land transportation mediums’ capacity to 20.

“ChangeCap@TSH_2” Assign Module: This assigns a new value of NQ(TSHLoad*N*.Queue) + 1 for the variable TransCap_TSHAPOE_*N*. *N* = 1. 2, …, 6. This sets the capacity to the current queue length (or number waiting to be batched) plus one for the current entity.

"TSHLoad*N*" Batch Module (for *N* = 1, 2,…, 6): This is Temporary type with batch size of TransCap_TSHAPOE_*N* (for *N* = 1, 2,…, 6). It also uses the save criterion as last and any entity rule.

"TSHLandTrans *N*" Process Module (for *N* = 1, 2,…, 6): This module uses the logic action of Seize Delay Release with Medium(2) priority; it uses one TSHLandTrans and has a constant delay set to the expression

$$Eqn\ (3.8): Delay = 1/(AvgLandTransSpeedmph / TSHAPOEDistance)$$

in hours. This is a standard type and uses value added allocation.

"Separate *N*" Separate Module (for *N* = 11, 12,…, 16): This module is a split existing batch and member attributes retain original entity values. This simulates the passengers on a bus or other land transport exiting the medium.

"Separate *N*" Separate Module (for *N* = 32, 33,…, 37): When the last entity goes through "HowManyLeft_3?" all the batches waiting to be filled to a certain capacity must be easily emptied – otherwise the simulation will not complete. The separate module is a duplicate original type with zero percent cost to duplicates and one (1) duplicate. Thus the last entity is duplicated in the separate modules *N*-1 times and the original entity and each duplicate clears out the *N* batch modules. The last separate module is a split existing batch and member attributes retain original entity values. (*N* = 6)

"ReceiveAPOE" Delay Module: This module uses the logic action of Delay and has a delay expression by the uniform distribution, UNIF(0.3,0.4) minutes, and uses the random number stream ten (10). This is a standard type and uses value added allocation.

“ProcessTransQueue_4” Process Module: This module uses the logic action of Seize Delay Release with Medium(2) priority; it uses one TransQStnsAPOESH and has a constant delay set to “DetProcessTime” variable value in minutes. This is a standard type and uses value added allocation.

“AwaitTrans_4” Process Module: This module uses the logic action of Delay and has a constant delay set to “DetWaitingTime” variable value in minutes. This is a standard type and uses value added allocation.

“NumEvactoTSH” Record Module: This is a Count type with value = 1. This counter represents all the entities that have made it to the TSH in the NEO system.

“HowManyLeft_4?” Decide Module: This module is an N-way by condition decide where N = 3. If NC(NumEvacthruSPOE) >= (TotalEvacuees + 18) , then the entities go to the “WhichTransSPOETSH?” Decide module. If NC(NumEvactoSPOE) >= (TotalEvacuees + 15), then the entities go to “ChangeCap@SPOE” module. Else entities go to “ChangeCap@SPOE_2” module. Once all entities have gone through the sea transportations’ capacities are lowered to recognize the system’s need to compensate for only a few entities left in the system. At the last entity, the second assign module changes all the capacities to one such that all entities move on and the separate modules are used to ensure all batching modules are emptied.

“WhichTransAPOESH?” Decide Module: This is an N-way by chance decide where N = 4. The chance values are set to 30, 25, 25, and 20 which lead into the four batch modules for transportation to the SH.

“CheckTransPick4” Dispose Module: This dispose module is a verification check; if any entities go to this module, then the decide module is not working properly.

“ChangeCap@APOE” Assign Module: This assigns a new value of one hundred (100) for each of the variables TransCap_APOESH_*N* for *N* = 1, 2, …, 4. The model effectively lowers all the land transportation mediums’ capacity to 100.

“ChangeCap@APOE_2” Assign Module: This assigns a new value of NQ(APOELoad*N*.Queue) + 1 for the variable TransCap_APOESH_*N*. *N* = 1, 2,…, 4. This sets the capacity to the current queue length (or number waiting to be batched) plus one for the current entity.

“APOELoad*N*” Batch Module (for *N* = 1, 2, …, 4): This is Temporary type with batch size of TransCap_APOESH_*N* (for*N* = 1, 2,…, 4). It also uses the save criterion as last and any entity rule.

“APOEASTrans*N*” Process Module (for *N* = 1, 2, …, 4): This module uses the logic action of Seize Delay Release with Medium(2) priority; it uses one AirSeaTransToSH and uses the uniform distribution, UNIF(2.5,3.5) hours, for the delay time. Also the expression uses random number stream eleven (11).

“Separate *N*” Separate Module (for *N* = 17, 18, …, 20): This module is a split existing batch and member attributes retain original entity values. This simulates the passengers on a plane or other aircraft exiting the medium.

“Separate *N*” Separate Module (for *N* = 38, 39, …, 41): When the last entity goes through “HowManyLeft_4?” all the batches waiting to be filled to a certain capacity must be easily emptied – otherwise the simulation will not complete. The separate module is a duplicate original type with zero percent cost to duplicates and one (1) duplicate. Thus the last entity is duplicated in the separate modules *N*-1 times and the original entity and each duplicate clears out the *N* batch modules. The last separate module is a split existing batch and member attributes retain original entity values. (*N* = 4)

"SHArrivalTimes*N*" Record Module (for *N* = 1, 2,…, 4): This records the SH arrival time for each entity in the Entity Statistics.

"Evacuees@SH*N*" Dispose Module (for *N* = 1, 2,…, 4): This dispose module is a represents each evacuees arrival to the SH.

Appendix D: Analysis Results and Assumptions Verifications

Appendix D contains all the output data and the Design-Expert® diagnostic graphs that confirm that the two designed experiments meet the required normality and independence assumptions. Be aware that all data is reported in hours unless otherwise noted.

Table D1. OFAT Planning Considerations Response Data

Rep	Baseline	S1	S	S2	S	S3	S
1	258.02	264.02	69706.56	258.02	66574.32	258.02	66574.32
2	282.76	264.03	69711.84	252.71	63862.34	257.08	66090.13
3	259.56	264.02	69706.56	253.97	64500.76	277.76	77150.62
4	278.90	278.45	77534.40	281.11	79022.83	278.90	77785.21
5	258.03	255.35	65203.62	252.03	63519.12	258.03	66579.48
6	275.07	279.39	78058.77	277.06	76762.24	275.07	75663.5
7	256.96	251.37	63186.88	252.03	63519.12	256.96	66028.44
8	294.02	284.06	80690.08	282.02	79535.28	294.02	86447.76
9	279.13	278.19	77389.68	278.70	77673.69	279.13	77913.56
10	278.55	283.10	80145.61	278.89	77779.63	278.55	77590.1
11	256.75	264.02	69706.56	253.98	64505.84	256.75	65920.56
12	272.19	264.02	69706.56	252.47	63741.1	272.19	74087.4
13	258.72	264.02	69706.56	261.03	68136.66	258.72	66936.04
14	258.40	264.02	69706.56	255.17	65111.73	258.40	66770.56
15	258.03	284.03	80673.04	282.03	79540.92	258.03	66579.48
16	260.13	264.02	69706.56	278.91	77790.79	259.41	67293.55
17	258.31	264.03	69711.84	253.33	64176.09	254.45	64744.8
18	255.32	264.02	69706.56	282.03	79540.92	255.24	65147.46
19	259.02	264.03	69711.84	252.04	63524.16	258.04	66584.64
20	282.02	275.67	75993.95	270.02	72910.8	282.02	79535.28
Avg	266.99	268.69	275.84	266.34	272.583	266.34	273.5173
StDev	11.89	9.58		13.03		11.91849	

Table D2. OFAT Diplomatic Considerations Response Data

	Number of Port Slips				
Replication	1	2	3	4	5
1	480.02	258.02	202.6	204.24	202.61
2	480.03	282.76	203.22	206.82	203.81
3	474.02	259.56	210.94	210.03	210.03
4	494.47	278.9	210.03	210.03	207.12
5	567.66	258.03	230.92	204.38	207.4
6	493.75	275.07	210.03	210.03	210.03
7	469.38	256.96	204.43	210.03	210.03
8	504.02	294.02	210.02	204.73	208.51
9	501.01	279.13	210.03	210.03	206.73
10	495.11	278.55	210.02	205.68	207.43
11	493.45	256.75	206.24	208.12	210.93
12	500.66	272.19	210.23	206.73	208.27
13	495.03	258.72	206	206.49	206.73
14	471.93	258.4	206.46	204.29	210.03
15	499.5	258.03	210.03	205.55	208.14
16	480.81	260.16	210.03	210.03	205.12
17	534.03	258.31	210.03	210.03	207.52
18	492.32	255.32	205.37	210.03	204.55
19	499.2	259.02	204.64	206.8	210.04
20	504.02	282.02	210.57	202.1	207.53
Average	496.521	266.996	209.092	207.3085	207.628
Std Dev	22.14234	11.88978	5.835525	2.595922	2.279849
Marginal Imp		229.525	57.904	1.7835	-0.3195

Table D3. ECC Experiment Response Values

ECC Process Speed	ECC Schedule	No. of ECC	Process Stns After ECC	MaxAvg LastTSHTime
Fast	DoS_16	6	12	111.1
Mixed	DoS_16	2	12	107.74
Slow	DoS_16	2	6	107.82
Fast	DoS_20	2	12	110.47
Fast	DoS_16	2	6	107.63
Mixed	DoS_16	2	6	107.64
Slow	DoS_20	2	12	109.79
Mixed	DoS_20	6	12	106.34
Slow	DoS_16	2	12	102.65
Mixed	DoS_16	6	6	102.21
Slow	DoS_20	6	6	106.04
Fast	DoS_16	2	12	107.74
Fast	DoS_16	6	6	111.45
Mixed	DoS_20	6	6	111.84
Slow	DoS_16	6	6	107.92
Slow	DoS_20	2	6	106.11
Slow	DoS_20	6	12	105.76
Mixed	DoS_20	2	6	109.36
Slow	DoS_16	6	12	110.2
Mixed	DoS_20	2	12	106.17
Mixed	DoS_16	6	12	107.98
Fast	DoS_20	6	6	106.1
Fast	DoS_20	6	12	106.16
Fast	DoS_20	2	6	106.24

Table D4. Major Resources Experiment Response Values

Run	No. of ECCs	No. of Port Spaces	No. of Planes	Avg Completion Time
12	2	3	4	205.662
6	2	3	5	207.3085
9	2	3	6	206.0895
2	2	4	4	208.253
17	2	4	5	205.8845
5	2	4	6	208.624
14	2	5	4	205.4215
10	2	5	5	209.2415
18	2	5	6	207.495
16	6	3	4	206.9605
15	6	3	5	206.8875
3	6	3	6	209.092
8	6	4	4	205.5195
11	6	4	5	207.628
13	6	4	6	206.309
4	6	5	4	208.8485
1	6	5	5	206.729
7	6	5	6	205.2805

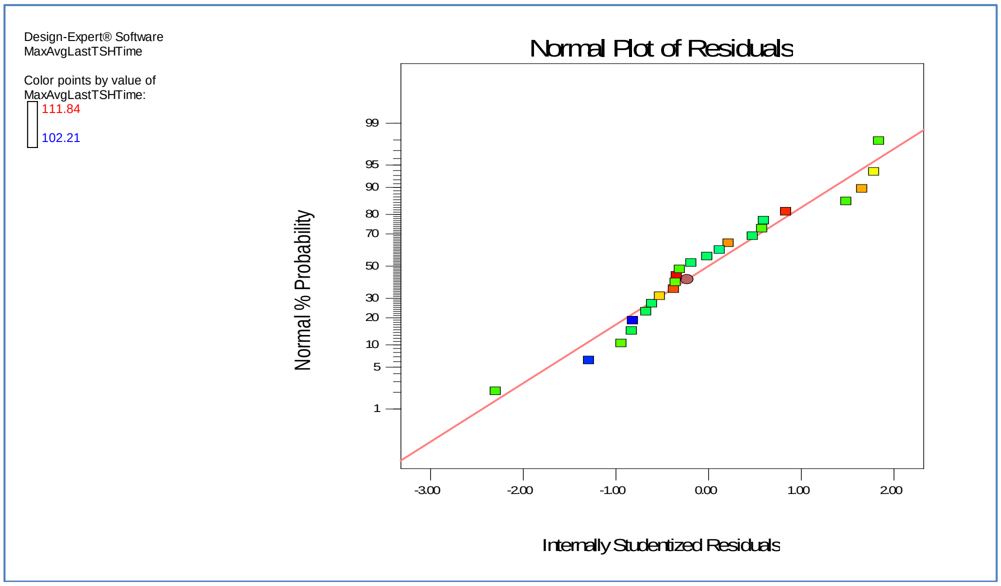

Figure D1. ECC Experiment: Normal Probability Plot

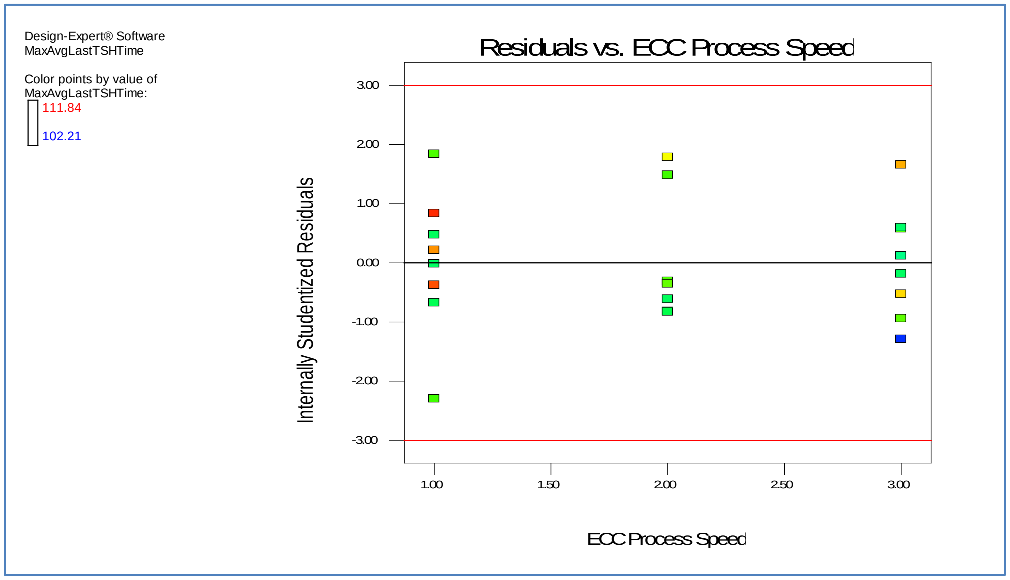

Figure D2. ECC Experiment: Residuals vs. ECC Process Speed (A)

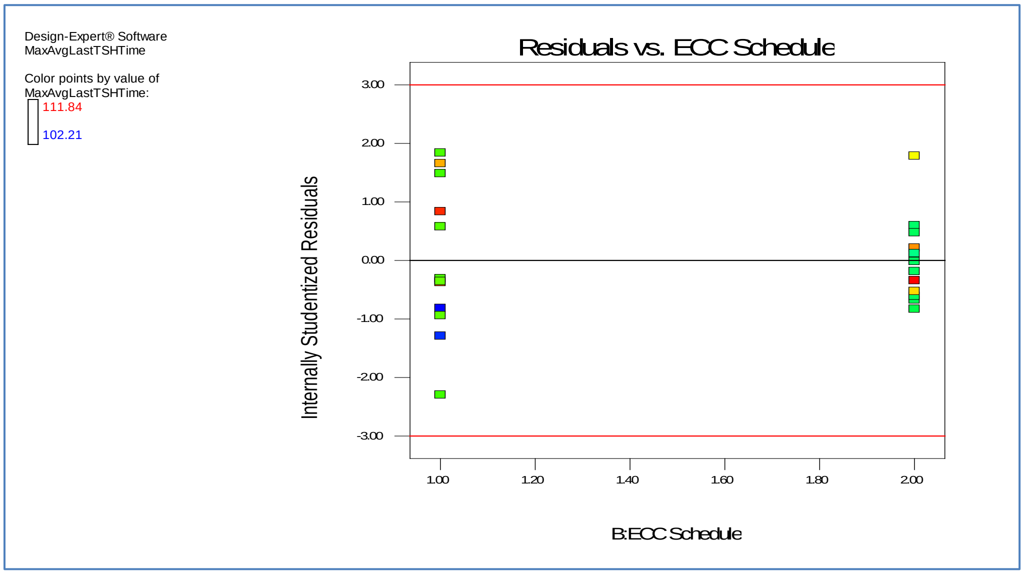

Figure D3. ECC Experiment: Residuals vs. ECC Schedule (B)

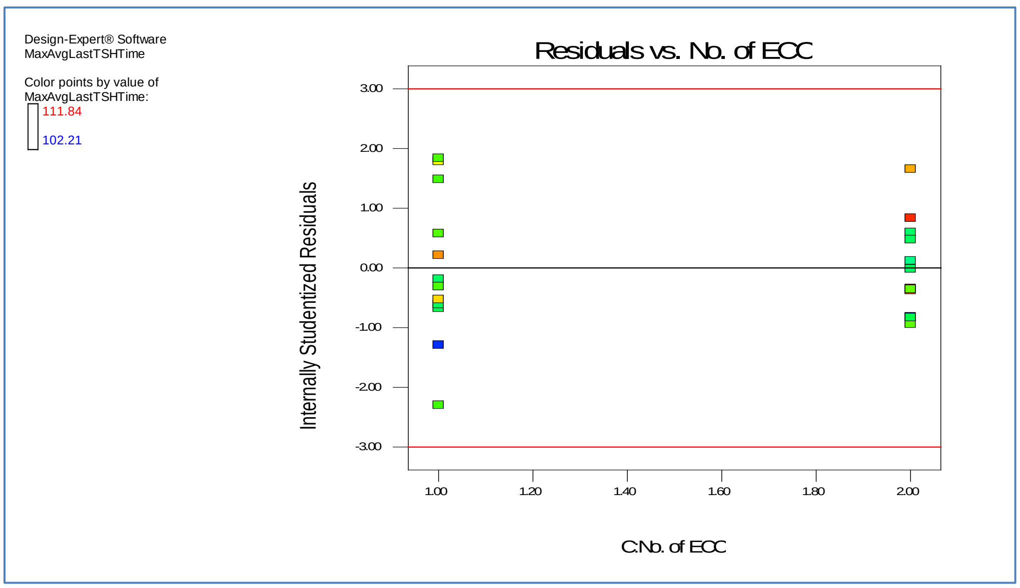

Figure D4. ECC Experiment: Residuals vs. No. of ECCs (C)

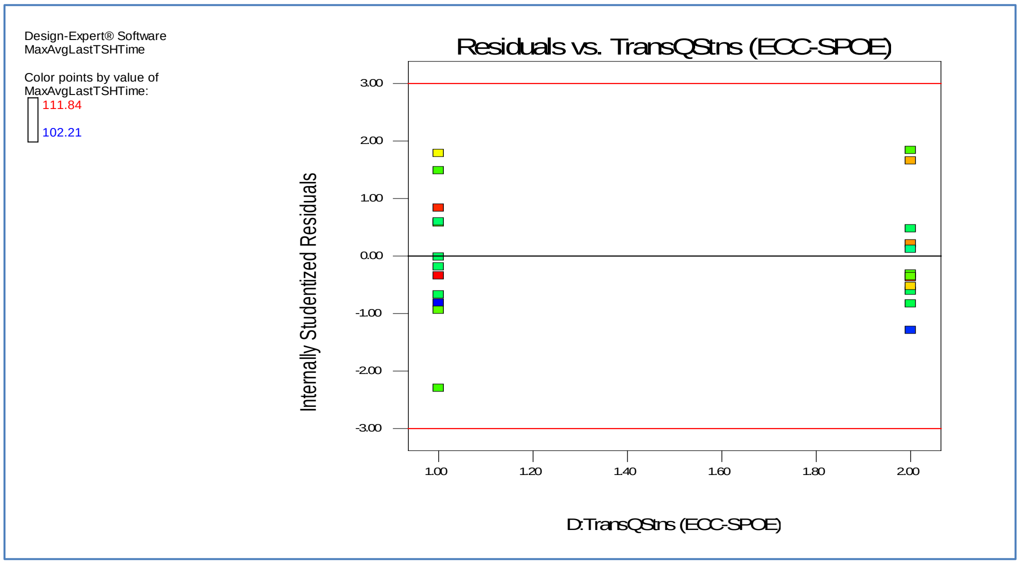

Figure D5. ECC Experiment: Residuals vs. SPOE Transportation Processing Stns (D)

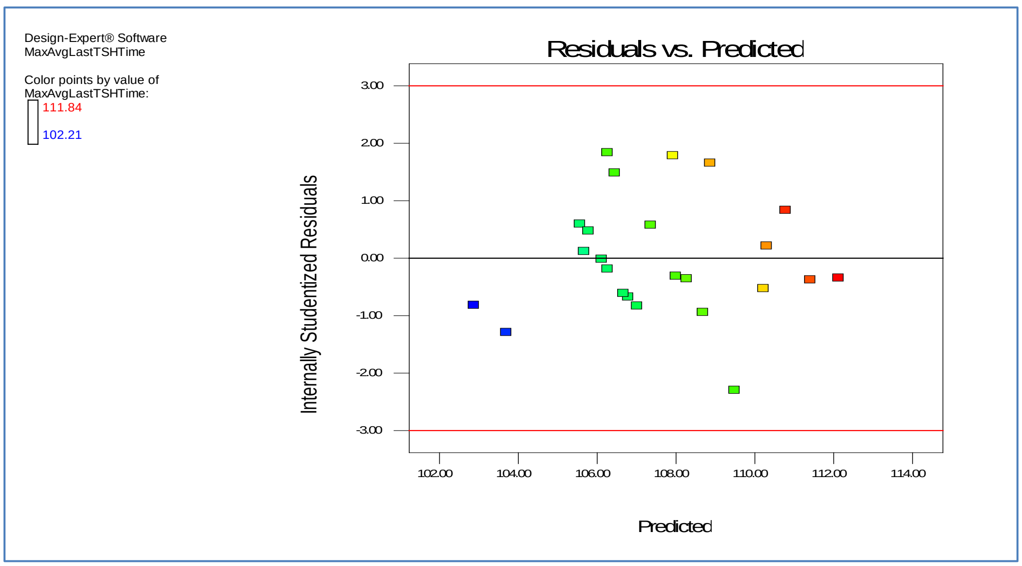

Figure D6. ECC Experiment: Residuals vs. Predicted

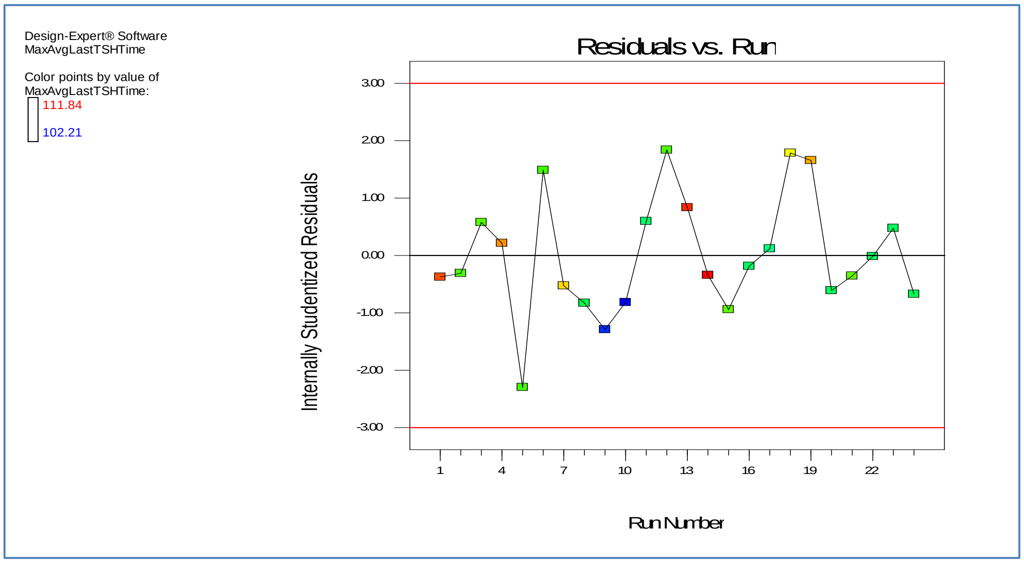

Figure D7. ECC Experiment: Residuals vs. Run Order

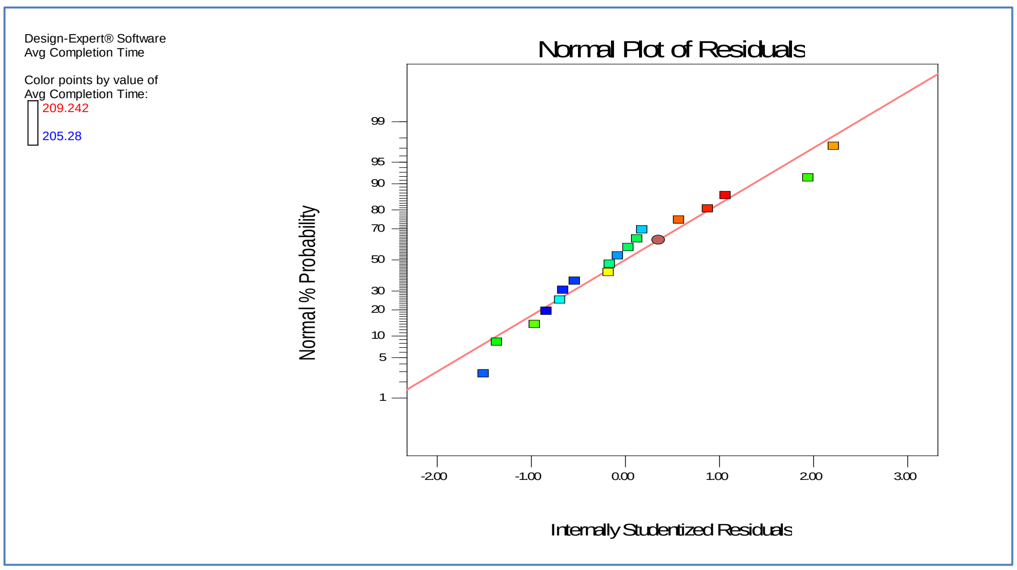

Figure D8. Resources Experiment: Normal Probability Plot

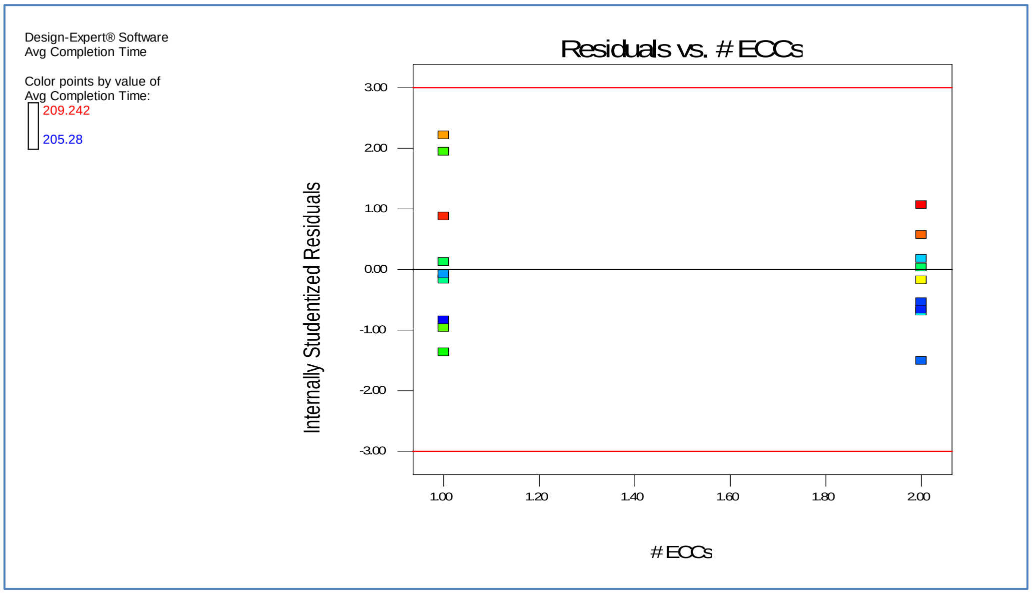

Figure D9. Resources Experiment: Residuals vs. No. of ECCs (A)

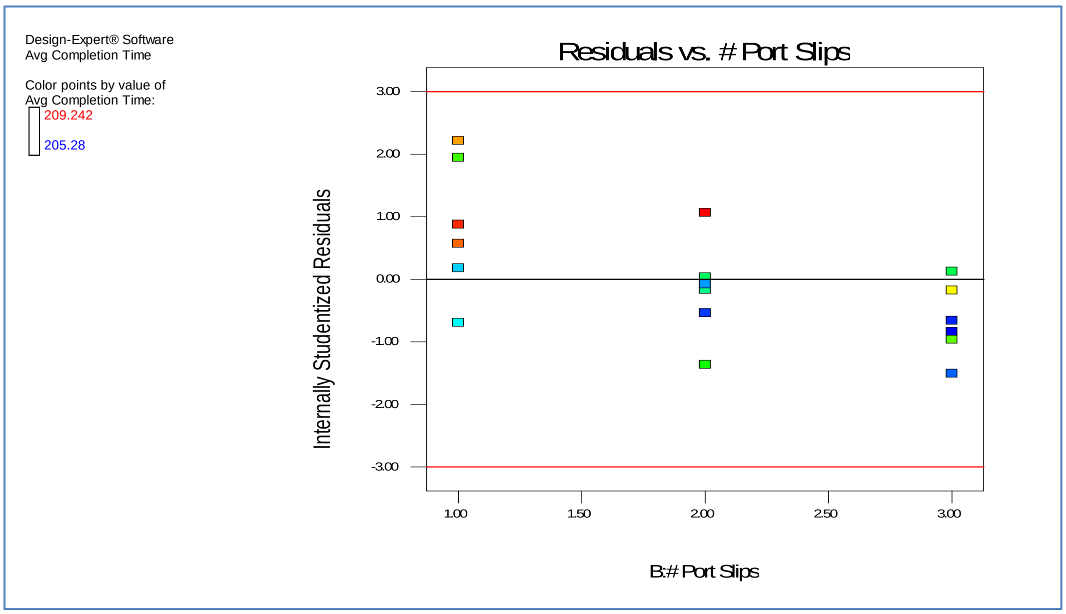

Figure D11. Resources Experiment: Residuals vs. No. of Port Spaces (B)

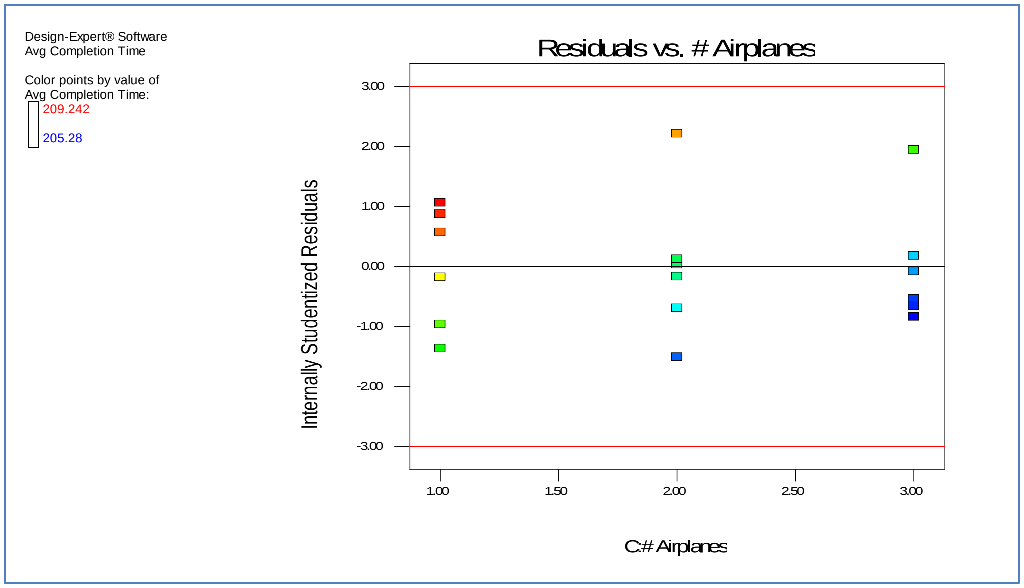

Figure D10. Resources Experiment: Residuals vs. No. of Airplanes (C)

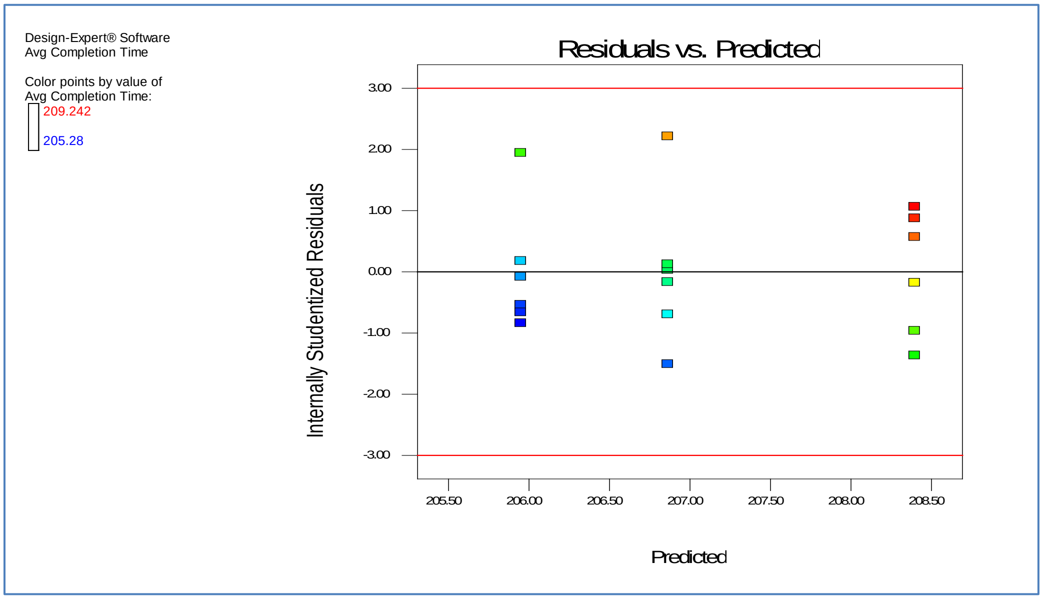

Figure D12. Resources Experiment: Residuals vs. Predicted

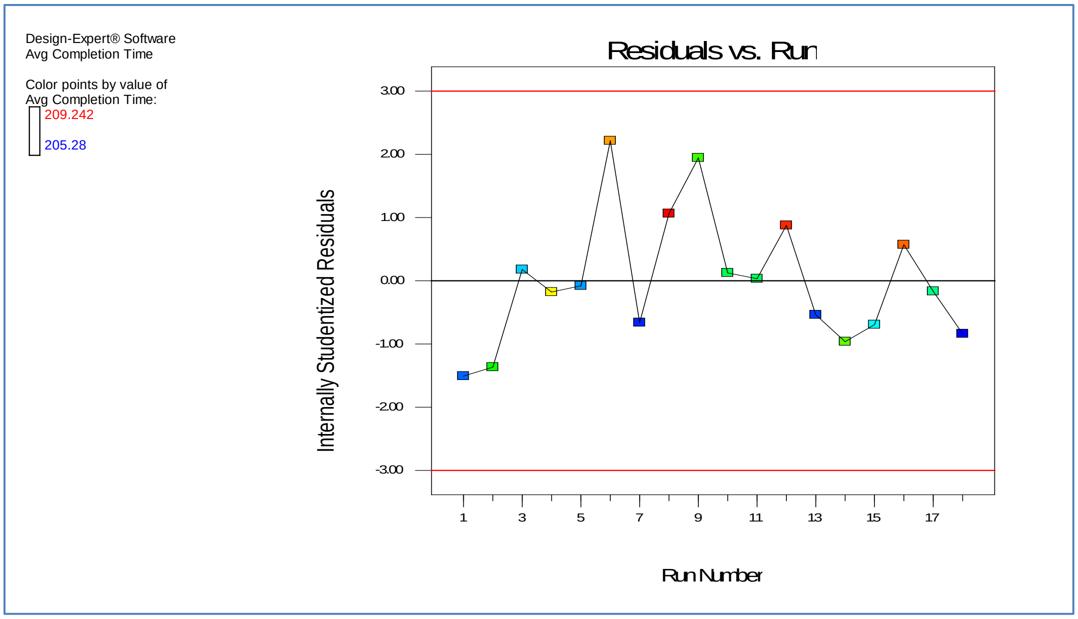

Figure D13. Resources Experiment: Residuals vs. Run Order

Appendix E: Air University Blue Dart

Noncombatant Evacuation Operations: Controlling the Chaos

Imagine being able to stop the ensuing madness of a typical evacuation operation before it starts. The Center of Operational Analysis (COA) within the Graduate School's Department of Operational Sciences at the Air Force Institute of Technology (AFIT) is attempting to do just that while continually forging new collaborative research relationships with operational sponsors. Doing so ensures the department's high quality research is operationally relevant by directly impacting the Air Force, DoD, and the National Security Structure of the United States. During the past year, the COA has partnered with United States European Command (USEUCOM) to develop an analytical framework for planning Noncombatant Evacuation Operations (NEO). Specifically, the Director of Operations (J3), Air Force Maj Gen Harold "Punch" Moulton recognized the unique capability of using technically gifted and operational experienced graduate students at AFIT to better capture the complexity intrinsic to the NEO system.

Unique in many ways, a NEO is the only military operation that is considered a diplomatic instrument of power; thus the Department of State (DOS) owns the process and has authority over the operation. Additionally, a NEO is often constrained by political considerations, U.S. resources, host nation resources, and time, which morph depending on an ever-evolving set of uncertain circumstances. Given this uncertainty, EUCOM Plans and Operation Center's (EPOC) Crisis Response Branch is responsible for NEO planning and requires a robust planning methodology in order to avoid or alleviate the detrimental effects of these constraints.

To alleviate the risks inherent to uncertainty in the NEO environment, a graduate research project developed a high-level analysis framework that assists military planners along with their DOS counterparts in identifying capacity deficiencies and system bottlenecks. Specifically, the NEO process is described as a system of similar cyclical segments consisting of (1) processing at a new arrival point; (2) processing to catch next transportation leg; (3) awaiting availability of next transportation medium (i.e., bus, ship, plane, etc.) and (4) traveling to next arrival point, where each segment is limited by finite resources (servers) to process each evacuee. This framework models the NEO process as series of queues in a discrete-event simulation using Arena software.

The resulting interactive tool allows DoD and DoS planners to replicate a general NEO scenario (or multiple scenarios) in order to describe, understand, and analyze any real-world evacuation operation making it possible to identify the most likely causes for delays or disruptions in the operation. Ultimately, these analytical insights will accentuate process areas where efficiencies can be gained. Together this knowledge will provide insight to planners for enhanced allocation of command resources and for areas to concentrate diplomatic efforts with the pertinent countries.

Appendix F: AFIT Research Newsletter Article (Published June 2010)

AFIT Research Supports Real-World Evacuation Planning

Recognizing the need for high-level simulation in contingency planning, Maj Gen Harold Moulton, Director of Operations (J3), United States European Command (USEUCOM), requested that AFIT's Center of Operational Analysis (COA) develop an analytical framework for planning Noncombatant Evacuation Operations (NEO). Maj Aimee Gregg, an Operations Analysis student in AFIT's Intermediate Developmental Education program, responded by creating a system model to replicate general NEO scenarios. "It was very rewarding to work on a project that could be applied to real-world operations," remarked Maj Gregg. Her graduate research project entitled "Optimizing Crisis Action Planning in the Noncombatant Evacuation Operation Setting," describes how EUCOM planners can use her analytical model to enhance contingency planning and diminish the risks of uncertainty in a NEO operation.

Unique in many ways, a NEO is the only military operation that is considered a diplomatic instrument of power. Therefore, the Department of State (DOS) is the lead government agency and has authority over the operation. Additionally, a NEO is constrained by political considerations, U.S. resources, host nation resources, and time. These factors morph as the scenario evolves inducing a large amount of uncertainty and complexity into the planning process. Maj Gen Moulton relies on his EUCOM Plans and Operation Center's (EPOC) Crisis Response Branch to anticipate the impact of these circumstances and develop robust plans for NEO contingencies.

Maj Gregg's framework assists EPOC and DOS planners in this enormous task by providing them a simulation tool to describe, understand, and analyze real-world evacuation operations. This analytical model enables planners to identify potential bottlenecks in NEO situations and thus improve efficiency. "One of the great things about this project is that this tool can facilitate more effective communication between the component planners," commented Maj Gregg. Armed with analytical insight from her simulations, EUCOM planners can work to establish joint and interagency procedures that focus all available government resources on these potential chokepoints. Maj Gregg's research advisors were professors Maj Shane Hall and Dr. J.O. Miller.

Look for other exciting research results from AFIT's Center of Operational Analysis in the Graduate School of Engineering and Management 2010 Annual Report due to be released this winter.

Appendix G: List of Acronyms

Acronym	Term
ABM	Agent-Based Modeling
AFIT	Air Force Institute of Technology
AOI	Area of Interest
AOO	Area of Operations
AOR	Area of Responsibility
API	Application Programming Interface
APOD	Aerial Point/Port of Debarkation
APOE	Aerial Point/Port of Embarkation
ANOVA	Analysis of Variance
BP	British Petroleum
CJTF	Commander Joint Task Force
COM	Chief of Mission
CONPLAN	Contingency Plan
DARPA	Defense Advanced Research Projects Agency
DES	Discrete Event Simulation
DoD	Department of Defense
DoS	Department of State
DSS	Decision Support System
EAP	Emergency Action Plan
ECC	Evacuation Control Center
EOC	Emergency Operations Center
EPOC	EUCOM Plans and Operations Center
ERP	Evacuation Routing Problem
EUCOM	European Command
FCE	Forward Control Element
FCFS	First Come, First Served
FEMA	Federal Emergency Management Agency
FRG	Federal Republic of Germany
GCC	Geographic Component Commander
GUI	Graphical User Interface
HLS	Homeland Security
HN	Host Nation
HNS	Host Nation Support
IMDE	Integrated Model Development Environment
IOP	Instrument of Power
ISH	Intermediate Safe Haven
JP	Joint Publication
JTF	Joint Task Force

Acronym	Term
LCAC	Landing Craft Air Cushion
LCU	Landing Craft, Utility
MARFOREUR	Marine Corps Forces, Europe
MOE	Measure of Effectiveness
MOG	Maximum on Ground
MOOTW	Military Operations Other Than War
MOP	Measure of Performance
NATO	North Atlantic Treaty Organization
NAVEUR	Naval Forces Europe
NC	Number Counted
NCA	National Command Authorities
NEO	Noncombatant Evacuation Operation
NQ	Number in Queue
NTS	NEO Tracking System
OFAT	One Factor At a Time
OO	Object-Oriented
OPLAN	Operation Plan
OR	Operations Research
PERT	Program Evaluation and Review Technique
POL	Petroleum, Oil, Lubricants
SD	System Dynamics
SH	Safe Haven
SME	Subject Matter Expert
SOCEUR	Special Operations Command Europe
SOP	Standard Operating Procedure
SPOD	Sea/Surface Port of Debarkation
SPOE	Sea/Surface Port of Embarkation
TCN	Third Country National
TSA	Transportation Security Agency
TSH	Temporary Safe Haven
TTP	Tactics, Techniques and Procedures
US	United States
USAEUR	U S Army Europe
USAFE	U S Air Forces Europe
USEUCOM	United States European Command
USG	United States Government
USMC	U S. Marine Corps
USN	U S. Navy
WIP	Work in Progress

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Vita

Major Aimee N. Gregg is a native of Mt. Zion, IL and graduated with a Bachelor of Science in Mathematics from Baylor University; Waco, TX. Earning a four-year ROTC scholarship, her Air Force career began as a cadet, and she was commissioned in 1997. Major Gregg started as an Operations Analyst at the Air Force Research Lab at Kirtland AFB, NM. During her tour, she participated in many DoD basic research and development (R&D) projects in the high power microwaves field. In 2000, Major Gregg was assigned to the 36th Electronic Warfare Squadron at Eglin AFB, FL as an Assistant Flight Commander and oversaw the test design and analysis of several major ACC platforms including Foreign Military Exploration (FME) testing and design of experiments (DOE) training. In 2004 at Hurlburt AFB, FL, she moved to Air Force Special Operations Command's 18th Flight Test Squadron as the Analysis Flight Commander where she championed DOE techniques and directed major testing initiatives for the CV-22, AC-130, MH-53 and PC-12. For the 2007 AF Operations Research Symposium (AFORS), she served on the steering and planning committee. Between 2005 and 2009, Major Gregg served in career broadening assignments as a SOS Instructor and the 336th Recruiting Squadron Operations Flight Commander. From Aug 2007 to Feb 2008, she deployed to Ar Rustimayah, Iraq as the Student Squadron Commander for the Iraqi Air Force's (IAF) Officers Course where her team oversaw the professional development of over half of the existing IAF officer corps for 2008.

Following graduation from AFIT, she will serve as a staff officer at the 48th Fighter Wing Headquarters at RAF Lakenheath, United Kingdom.

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14. ABSTRACT

The purpose of this research was to improve the understand of and insight into the Noncombatant Evacuation Operation (NEO) system as doctrinally described in Joint Publication 3-68 and executed by European Command Plans and Operations Center with the strategic goal to increase command resource efficiency and decrease evacuation time. Further, the research objectives included improving the joint planners' insight into building more robust contingency and operational plans; highlighting chokepoints, bottlenecks, flow limiters, and options to quicken queues; and identifying resources and transportation mediums that display the most sensitivity to policy changes. These objectives were addressed by exploring topics in NEOs, evacuation planning, queueing systems, and modeling techniques and applications – particularly in computer simulation. The method chosen to model the NEO system and thus achieve the research objectives was a discrete event simulation model translated by the use of the Arena® simulation software. The model was developed by using a 12-Step simulation study procedure. Due to the lack of sufficient input data, the created model was able to be fully validated; yet several insightful results were gleaned from the planned experiments. Specifically, the model was unable to replicate a NEO's complexity and identify several areas where evacuee flow is constrained. It also highlights how to more effectively distribute command-controlled resources.

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